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GRAPHITE COMPOSITE LANDING GEAR COMPONENT — UPPER DRAG BRACE FOR F-15 AIRCRAFT

CLEVELAND PNEUMATIC COMPANY
3781 EAST 77th STREET
CLEVELAND, OHIO 44105

SEPTEMBER 1977

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Final Report for Period July 1975 – January 1977

AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

George J. Sperry
Project Engineer

Howell K. Brewer
Howell K. Brewer, Chief
Mechanical Branch (FEM)
Vehicle Equipment Division

FOR THE COMMANDER

Ambrose B. Nutt
Ambrose B. Nutt, Director
Vehicle Equipment Division (FE)

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This report summarizes work performed to design, fabricate and test a graphite epoxy composite material upper drag brace suitable for direct replacement of the current titanium upper drag brace for the F-15 aircraft landing gear assembly. Design, fabrication, test procedures, test results, and failure analysis are presented in detail. The composite material brace failed at less than design load. The program established, at the present time, that drag braces and similar landing gear hardware can not be satisfactorily fabricated from graphite epoxy material for use as a direct replacement of existing over

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metallic hardware in some applications. The volume and shape of available space in these direct replacement applications does not normally allow the use of optimum graphite epoxy material design and fabrication techniques. However, as demonstrated by the successful development of a graphite epoxy side brace suitable for direct replacement of existing metallic hardware on the A-37B aircraft, weight and cost saving applications to current aircraft are feasible. Therefore, each potential application must be individually evaluated. Work is required to improve analytical, fabrication and non-destructive inspection techniques for graphite epoxy materials. It can be reasonably expected that current and future efforts by the Air Force, industry and the educational community, aimed at these improvements, will increase the profitable application of graphite epoxy material to landing gear hardware.

FOREWORD

This report was prepared by the Cleveland Pneumatic Company, Cleveland, Ohio, under Air Force Contract F33615-75-C-3152 for the Mechanical Branch (FEM), Vehicle Equipment Division, Air Force Flight Dynamics Laboratory (AFFDL), Wright-Patterson Air Force Base, Ohio. The work was conducted under Air Force Project 1369, Mechanical Systems for Advanced Military Flight Vehicles, Task 136903, Mechanical Subsystems for Advanced Military Flight Vehicles.

The objective of this program was to demonstrate that landing gear hardware such as drag braces could be fabricated from graphite epoxy material and used as direct replacement hardware for current metallic hardware with resulting weight, and initial and maintenance cost, improvements. The program involved the design, fabrication and test of a graphite epoxy drag brace suitable for use on and as a direct replacement for the current titanium component used on the F-15 aircraft.

The authors wish to express their appreciation to the personnel of the Mechanical Branch, Vehicle Equipment Division, AFFDL for their assistance during this program. These individuals are: Gerald C. Shumaker, Capt. Peter F. Dexter, Kenneth P. Schwartz and George J. Sperry.

This report covers research conducted from July 1975 to January 1977 and was submitted in August 1977.

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SECTION I

INTRODUCTION

The use of advanced composite materials in landing gear hardware has the potential of saving both weight and cost. This study was conducted for the Air Force Flight Dynamics Laboratory (AFFDL) with the objective of advancing landing gear technology through the use of composite materials in current landing gear hardware. However, design and fabrication difficulties were encountered in a replacement design due to the complex, high concentrated load-carrying structure being replaced. Consequently, at this time the cost of the replacement is prohibitive and weight reduction is less than potentially available.

Prior AFFDL efforts have demonstrated the feasibility of fibrous composite landing gear brace hardware for a small Air Force trainer (A-37B) type aircraft. That contract resulted in the development of hardware that has successfully withstood the static ultimate loads and fatigue load spectrum of the corresponding metal hardware, demonstrating that small scale composite material linkages are feasible. That effort is detailed in AFFDL-TR-73-69, Graphite Composite Landing Gear Components--Side Brace Assembly and Torque Link for A-37B Aircraft. In addition, the side brace has successfully completed extensive environmental and load laboratory testing, and in-service flight testing. The results of this work are contained in AFFDL-TR-77-56, Development Tests and Flight Test of a Graphite Epoxy Landing Gear Side Brace Assembly for an A-37B Aircraft.

This program applied the technology associated with the A-37B graphite epoxy drag brace (linkage) hardware to the landing gear of a current Air Force fighter aircraft, the F-15, and further, assessed the fabrication cost and weight of composite materials for this type of application.

Accordingly, this program involved the design, fabrication, and testing of a graphite epoxy upper drag brace for the F-15 main landing gear. The hardware developed had to be completely interchangeable with the production upper drag brace (Cleveland Pneumatic Company Part No. 1915-73) and capable of being attached to the F-15 main gear using the production mating hardware. Thus, it was envisioned that the composite brace would serve as a replacement for existing titanium braces and also for future production assemblies.

The objective of testing the composite upper drag brace to the design static and fatigue loads was not achieved because of the early failure of the braces during the proof load cycle.

The program established that, at the present time, hardware such as drag braces could not be successfully fabricated from graphite epoxy materials for use as a direct replacement component for many existing aircraft due to space limitations and current limitations in graphite epoxy material analytical, fabrication and non-destructive inspection techniques. Each possible weight and cost saving application of graphite epoxy material to

landing gear hardware must be individually evaluated. New aircraft landing gear designs have high potential for the use of graphite epoxy composite material hardware because the specific volume and shape of available space is not fixed. This allows the use of design and fabrication techniques which will result in optimum weight and cost savings.

SECTION II
MATERIALS SELECTION

A. GRAPHITE-EPOXY SYSTEM

The primary requirement of the graphite composite material is high strength in tension, compression, and shear. Additional requirements include fatigue resistance, a balance of properties such that reasonable strain can be achieved, and sufficient stiffness to ensure that large deflections are not permitted. Prepreg requirements include long shelf life, good tack, low volatiles, and moderate flow. Temperature extremes for this application are moderate, -65^{o} to $160^{o}F$.

The material selected for use in the fabrication of the previous A-37B aircraft components was Hercules 2002T prepreg. During that program, but separate from it, Hercules developed improved fibers and new resins for similar load conditions, specifically the 2525/AS system. The latter was used independently to successfully fabricate and test another set of A-37B components, thus confirming the improved 2525/AS composite.

Prior to initiation of this program, a further composite improvement was developed, the 3501/AS system, which has direct application to this complex, load-carrying requirement. The lamina properties of

this composite are presented below. This material provides greater overall strength in fabrication and was thus used in the development of the F-15 upper drag brace.

TABLE 1

3501/AS GRAPHITE COMPOSITE LAMINA PROPERTIES

Elastic Constants at 77°F	
0° Tensile Modulus	18.0×10^6 psi
0° Compression Modulus	18.0×10^6 psi
90° Tensile Modulus	1.2×10^6 psi
90° Compression Modulus	1.2×10^6 psi
Shear Modulus	0.65×10^6 psi
Ultimate Strengths	
0° Tension	195,000 psi
0° Compression	195,000 psi
90° Tension	8,000 psi
90° Compression	35,000 psi
In-Plane Shear	8,000 psi

B. BONDING ADHESIVE

The basic requirements of the bond adhesive relate to both strength and ease in fabrication. Even though high shear strength in the temperature range of -65° to 160°F. and high fatigue resistance are essential to proper functioning of the fabricated F-15 drag brace,

complex fabrication techniques demand optimum production properties of room temperature cure, good surface wetting of plastic matrix composite, good characterization, and moderate viscosity.

Of the candidate bonding adhesives considered in Table 2, Hysol's EA934 two-part adhesive best satisfied the above requirements. Hysol's 934 cures at room temperature and was better characterized than most. The allowable shear stress is 7,800 psi at room temperature, based upon vendor test data and analysis as summarized in Appendix A. These test data represent average strengths as a function of temperature and were used in establishing design allowable stress.

TABLE 2

ADHESIVE SURVEY

Material	Cure Temp. (^{o}F.)	Viscosity	R.T.* Lap Shear Strength	Comments
Hysol 901-bl	R.T.	Thixotropic Paste	2,800 psi; 24 hr cure	High viscosity; rapid decrease in strength at higher temperatures (R.T. cure); 1,100 psi at 150^{o}F
Hysol 934	R.T.	Thixotropic Paste	3,100 psi; 7 days at 75^{o}F	High viscosity; maintains good strength over wide temperature range; better characterized than most
Hysol 943	R.T.	Thixotropic Liquids	1,500 to 1,800 psi; 5 days at 75^{o}F	Relatively low strength; high elongation at R.T. and above (60 to 70 percent)
Hysol 951	350	Film	6,320 psi; 1 hr at 350^{o}F	Film state; high temperature cure; excellent structural strengths; well characterized
Hysol 953	R.T.	Liquid	2,000 psi; 2 hr at R.T.	High elongation at R.T. and above (50 percent); moderately good shear strength at R.T.
Hysol 956	R.T.	Liquid	2,400 psi; 7 days at R.T.	Sister resin to 934 system; lower viscosity
FH1000	Elevated	Film	6,280 psi	Film state; elevated cure temperature; excellent structural adhesive for composites; well characterized
Uralane 5738	R.T.	Semi-paste	2,300 psi; 7 days at R.T.	High viscosity, high elongation at R.T. and above (200 percent); low elongation at low temperature
Uralane 5739	145 to 200		3,550 psi; cure not specified	Data generated by Lockheed; steel-to-steel shear strain at 80^{o}F - 150 percent; low strength at elevated temperatures

*R.T. = room temperature

SECTION III

DESIGN ANALYSIS

A. PRESENT DRAG BRACE HARDWARE

A view of the F-15 main landing gear arrangement and the graphite upper drag brace configuration is shown in Figure 1.

The present main gear upper drag brace, Part No. 1915-73, is shown in Figure 2. It is manufactured from titanium alloy (6Al-6V-2Sn) and is basically an "H" cross section with clevis lugs at each end connected by rails and supported by a shear web. The part is produced from a closed die forging weighing 24.75 pounds. The finished part is machined all over for configuration and weight control, with a minimum of 0.13 inch of stock removal per surface. The final weight of the machined part, without bushings, is 8.31 pounds. The attachment lugs are bushed with aluminum-nickel-bronze bushings and lubrication provisions are incorporated in the two apex lugs.

The titanium material in the final part is in the annealed condition and has 140,000 psi ultimate tensile strength and 81,000 psi ultimate shear strength.

The final part is protected against corrosion by application of one coat of primer and two finish coats of polyurethane enamel. The holes in the attachment lugs are protected with one coat of primer and the unplated bushings are installed with wet primer.

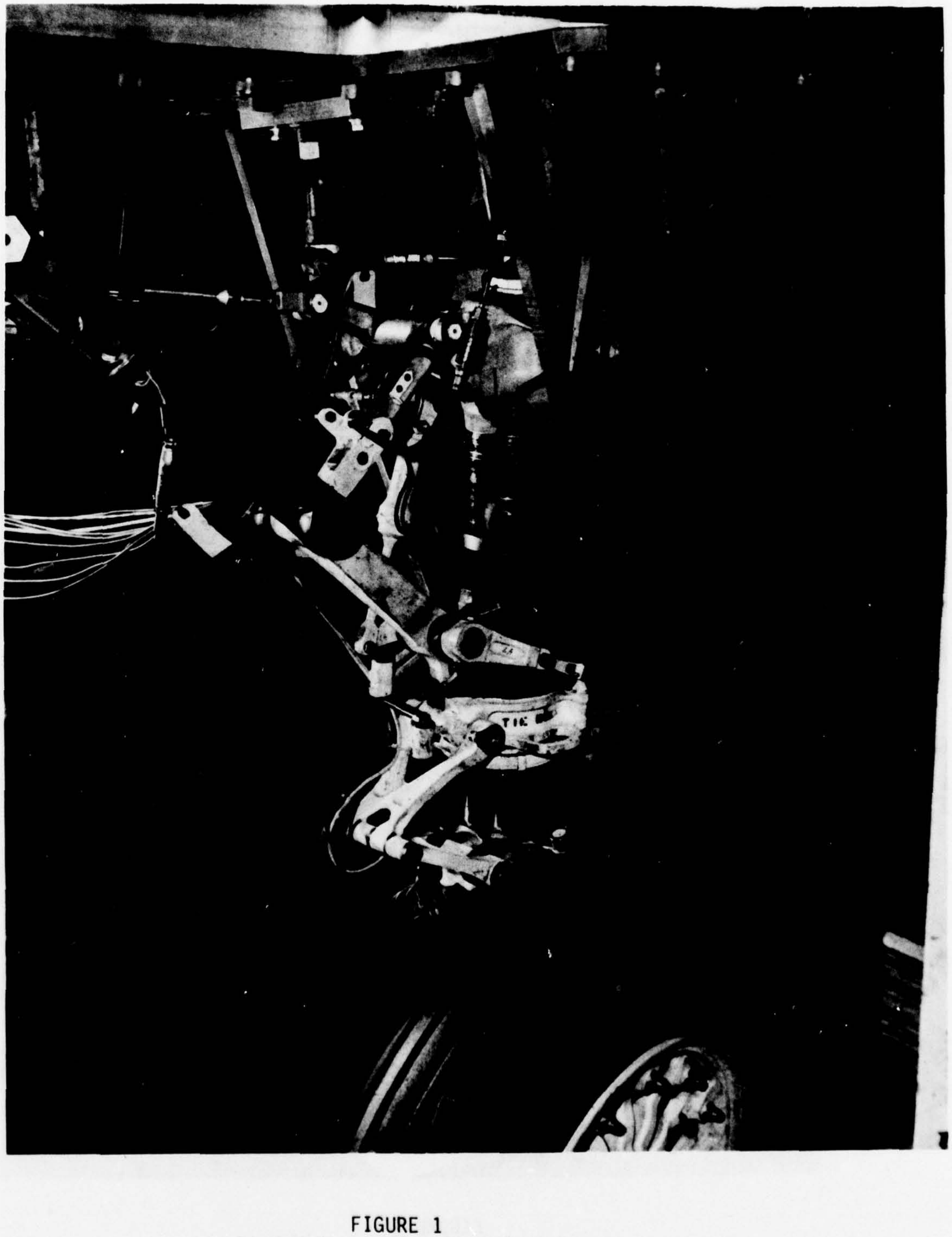


FIGURE 1
F-15 Main Landing Gear Arrangement

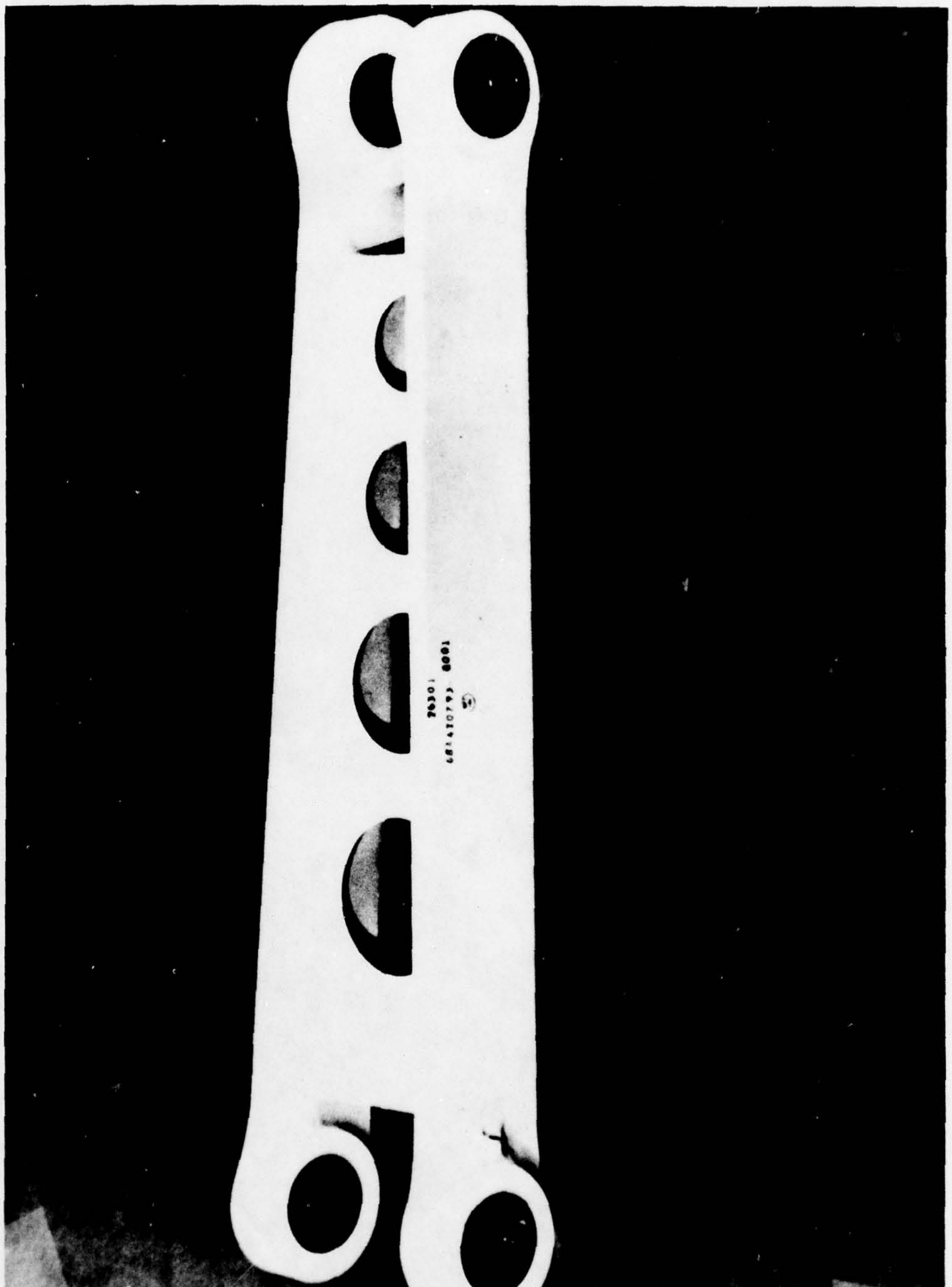


FIGURE 2
F-15 Main Landing Gear Upper Drag Brace

B. DESIGN CRITERIA

The upper drag brace developed during this program must be completely interchangeable with the present production upper drag brace and capable of being attached to the production version of the F-15 main gear. Specifically, the composite brace must be interchangeable to the extent that it can be installed on the F-15 main landing gear in place of the titanium brace with no modifications to any other hardware.

Critical clearance locations are:

- Upper lug attachment at the aircraft fitting
- Lower drag brace at the lower lugs when folding during retraction
- Leaf springs attached to the jury brace
- Fuel and gravity feed lines when the brace is stowed

The upper drag brace is designed for the landing and ground handling conditions specified in MIL-L-8552, with specific loads and fatigue spectrum defined by McDonnell Douglas Procurement Specification PS68-410052. The upper brace is a uniaxially-loaded member subjected to tension and compression forces resulting from ground loads applied at the wheel. The present upper brace was reviewed for all static load conditions and the braking conditions were found to be critical. Accordingly, the static design loads are a tension load of 153,600 pounds and a compression load of 156,300 pounds experienced during braking and reverse braking, respectively.

Basic cross-section size requirements of the present brace are determined by column analyses. The present part was analyzed about the strong axis, the pin-ended column including the upper and lower drag braces, and the weak axis, the pin-ended column of the upper drag brace only, and was found critical for column loading about the weak axis.

Further design analyses of the present brace showed:

- Critical lug loading is 40^{o} shear-out
- Bearing stress between the pin and bushings is limited to 135,000 psi ultimate, since the joints are static under the static design conditions
- Negligible cumulative fatigue damage for the specified load spectrum

The selected graphite epoxy system is not subject to deterioration when exposed to the environmental conditions of altitude, salt atmosphere, sand, and dust specified in MIL-STD-210. Likewise, there is no performance degradation when exposed to continuous operating temperatures in the range of -65^{o} to 160^{o} F. or to intermittent non-operating conditions of 364^{o}F. for one (1) minute or 300^{o}F. for ten (10) minutes.

C. BEARING DESIGN

The bushing material used in the existing metal drag brace attachment areas is nickel-aluminum-bronze, AMS 4880 castings heat-treated to 105,000 psi minimum tensile strength. Since the bushings and lubrication provisions have been fully tested, the same parts were used in the composite upper drag brace. In addition, thick-walled titanium inserts were specified for each end of the brace sides to distribute the high loads without deformation. The lubrication passages in the composite lugs were developed as part of the design requirement.

D. DRAG BRACE DESIGN EVOLUTION

In establishing the preliminary upper drag brace configuration within the specified design constraints, it was necessary to simultaneously consider:

- Optimization of the composite brace as a homogeneous material
- Bond line strength between dissimilar materials
- Shear and transverse tensile strength of the graphite epoxy material
- Fabrication technique

These considerations indicated the use of an "I" beam configuration similar to that reported in AFFDL TR73-60 for the A-37B aircraft composite side braces. Lugs on opposite ends of the brace are joined by a "racetrack" member as shown in Figure 3. An oriented-fiber

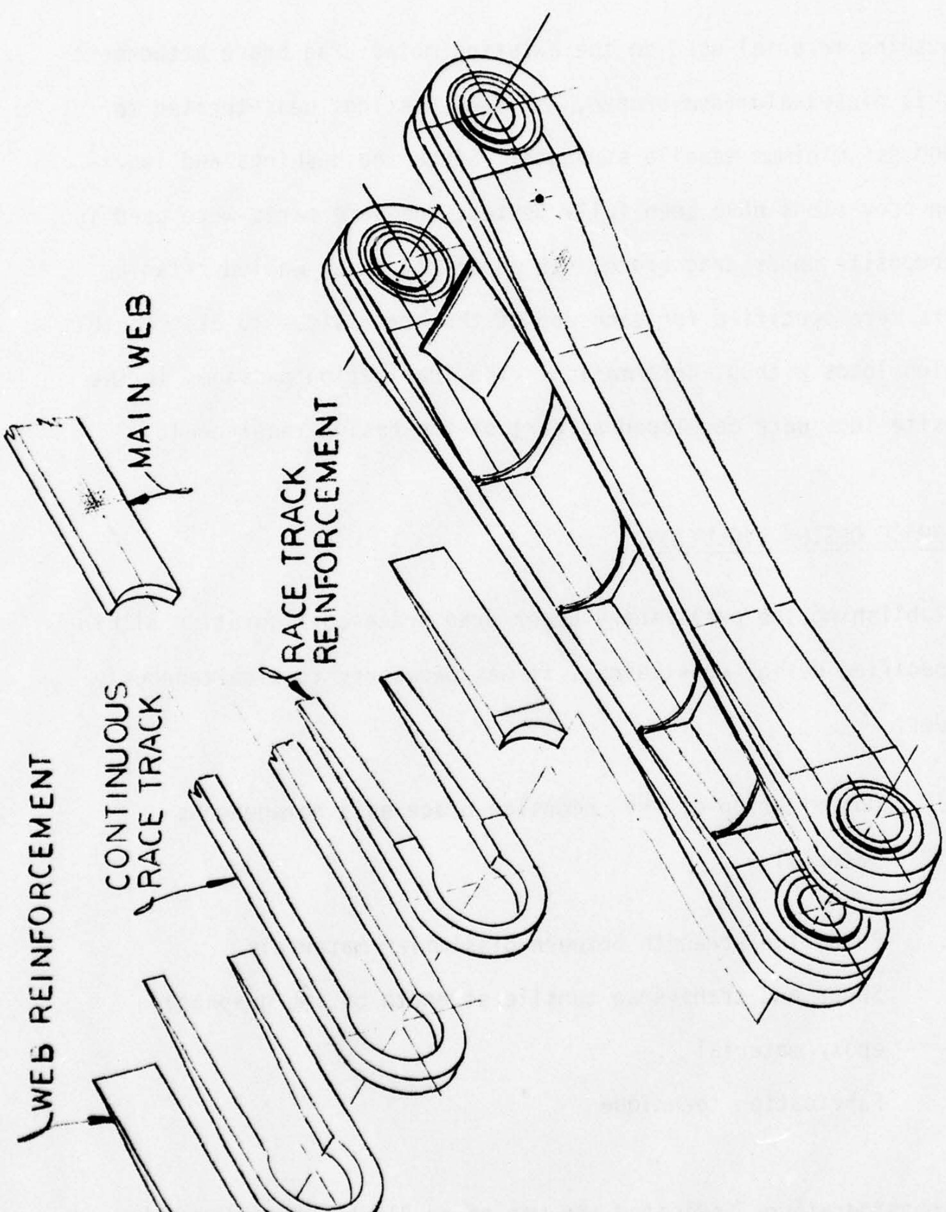


FIGURE 3
Upper Drag Brace Design Concept

web is positioned inside and perpendicular to the "racetrack" to achieve a rail section with adequate shear strength in the "I" section. Oriented-fiber bearing supports are bonded to the lugs to provide compression load strength and to improve load distribution. A pair of tapered raceways are then bonded on each end to complete the rail section.

An oriented-fiber channel section is bonded between the two rails to provide the shear web. For additional strength, gussets are bonded to the web and rails to complete the assembly.

The configuration is compatible with the fabrication technology demonstrated in the previous development program. Manufacturing consists primarily of placing unidirectional prepreg tape by hand to form basic laminate ply arrangements determined by analysis of estimated load paths. Because of the complex "I" shape, however, and the resultant shear and transverse tensile stresses under load, a much more complex laminate structure was required. To provide this additional transverse strength and structural integrity, a combination of 45^{o} and 90^{o} plies was added to the basic axial laminate arrangement. This is shown in the fiber orientation specification of Figure 4, the graphite epoxy upper drag brace fabrication drawing.

Of major concern in the determination of brace design, however, was the bonding of the titanium lugs (bushings) into the ends of the axial members. This problem involves both the low shear and transverse

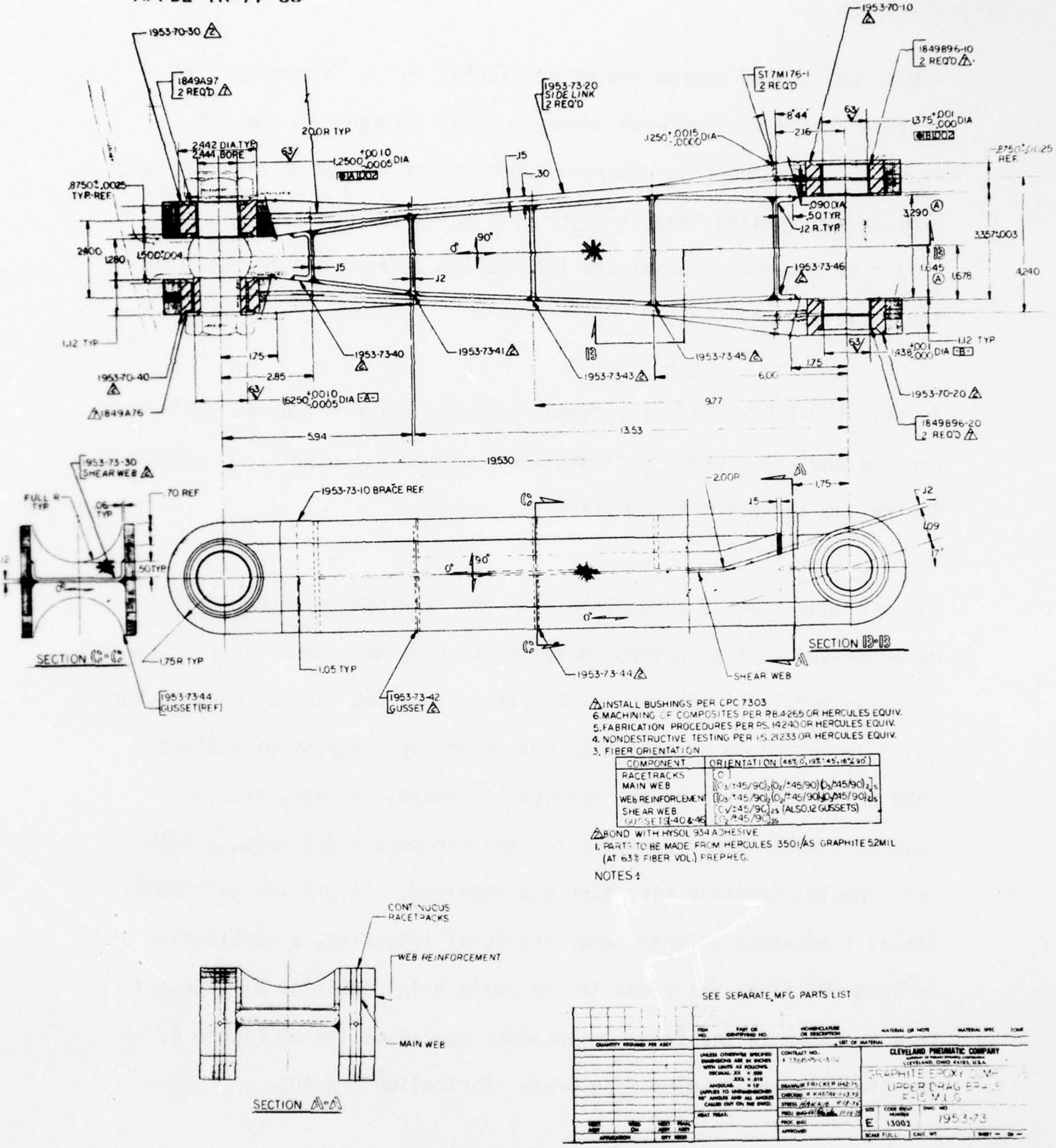


FIGURE 4
Graphite Composite Design for F-15 Upper Drag Brace

tensile strengths of the graphite epoxy material and the development of a bonding concept to transmit the high load stresses in the lug area. It is further complicated by the space envelope constraints.

Based on a finite element stress analysis which will be discussed in detail later, the lug end design evolution began with the concept of a slip-fit bushing having a radius of 1.50 inches and thickness of 0.875 inch, as shown in Figure 5. A second trial was made with the bushing bonded in place and a third concept incorporated a titanium spacer bonded in place to reduce the stresses in the composite materials. Both alternatives were unacceptable, resulting in negative margins of safety in the composite materials.

The next two concepts (Nos. 4 and 5) varied lug dimensions by increasing thickness to 1.00 and 1.25 inches, respectively, and by increasing radius, while evaluating the use of slip-fit titanium spacers. These also proved unacceptable.

In concept No. 6, a thicker, all composite lug at 1.72 inches radius was examined to determine additional stress data and in lug No. 7 the effects of bonded titanium bushings of various thicknesses were evaluated.

Ultimately, the bonding design illustrated as concept No. 8 was selected. This design reduces the stress concentration factor by use of a slightly larger bonded titanium bushing having a thickness of 1.12 inches and spacer radius of 1.21 inches. The spacer then tapers to an 0.875 inch thickness to maintain component interchangeability. The fabricated composite upper drag brace is shown in Figure 6.

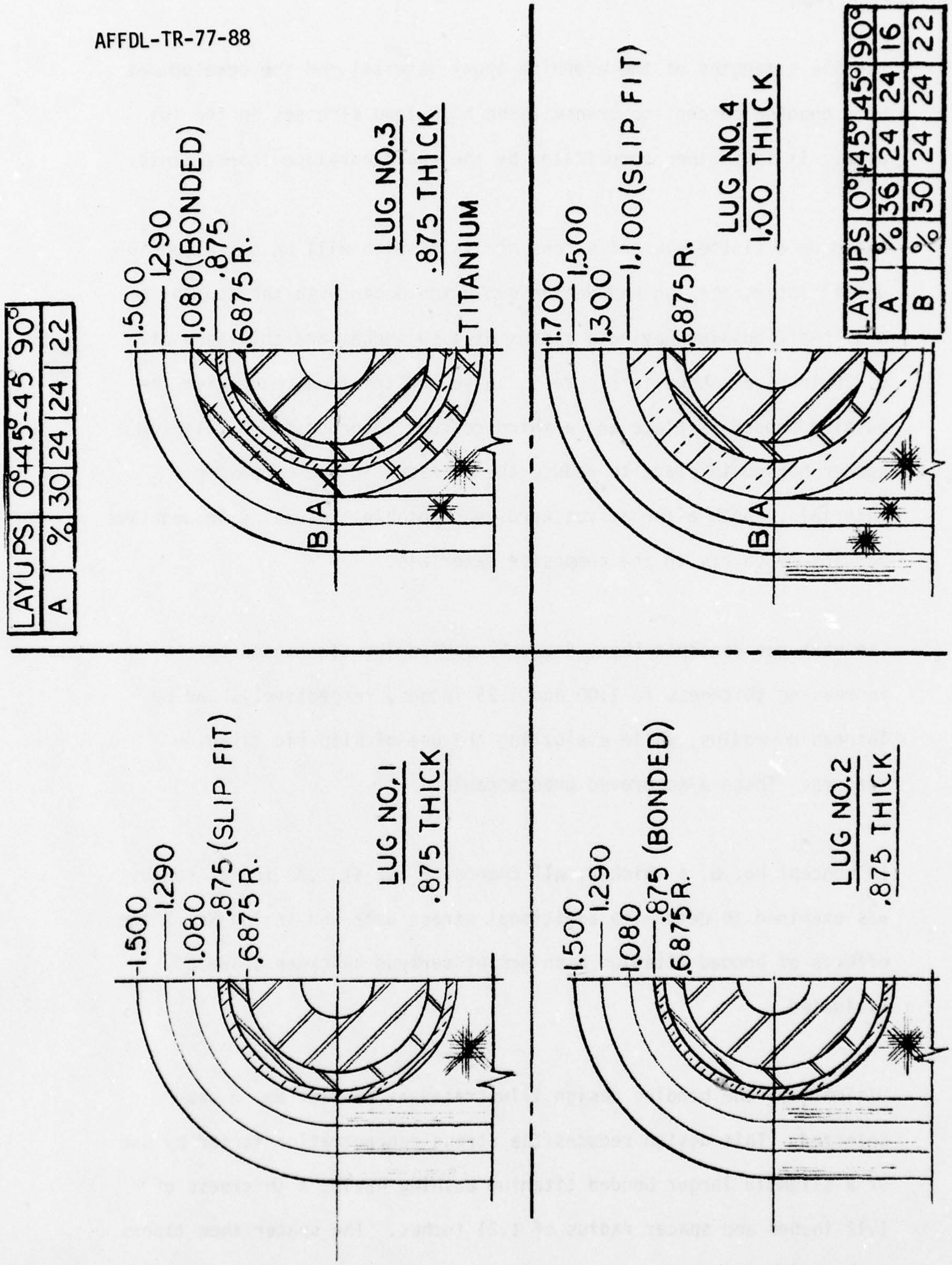


FIGURE 5-A
Lug Iterations

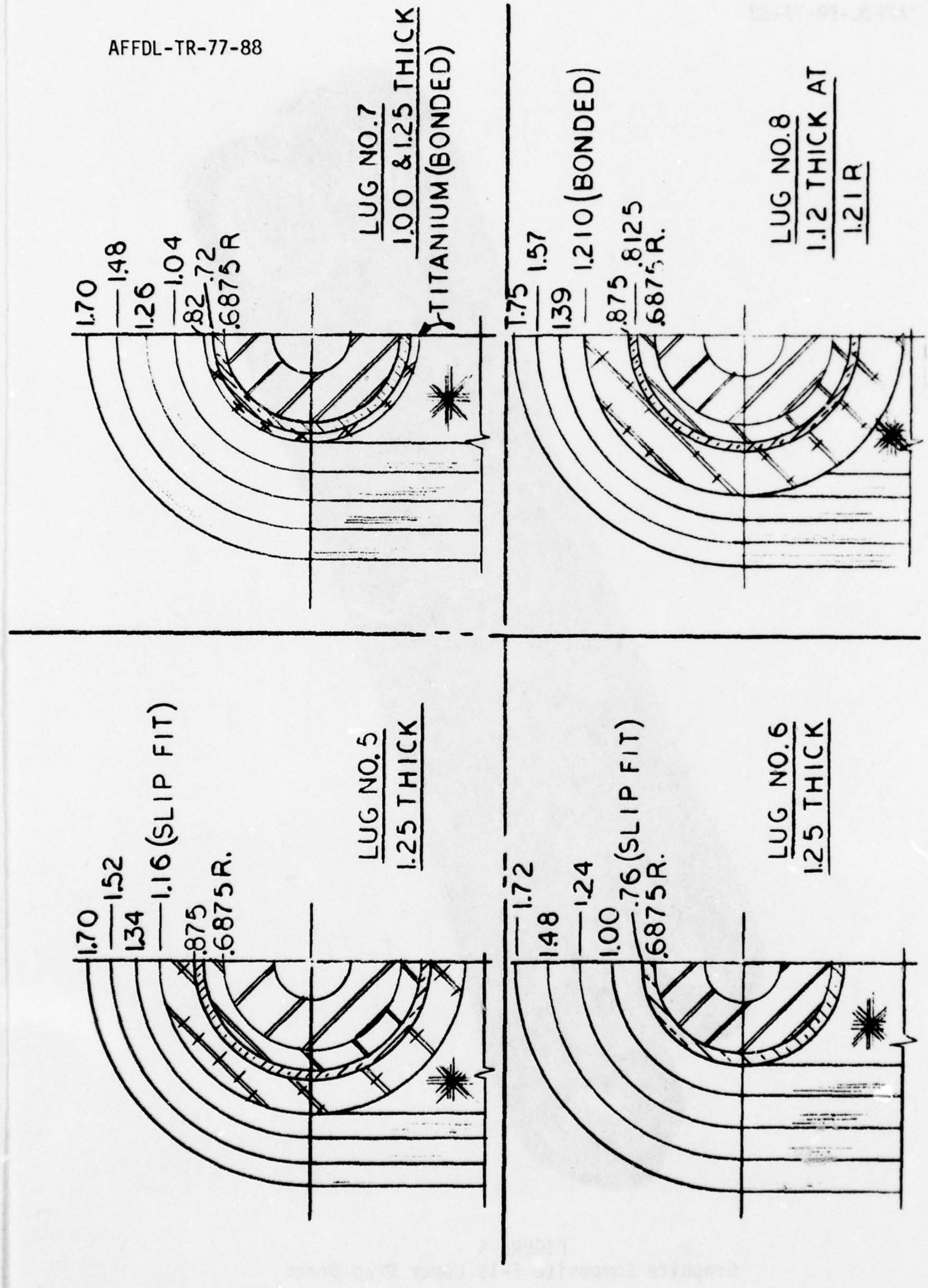


FIGURE 5-B
Lug Iterations

FIGURE 6
Graphite Composite F-15 Upper Drag Brace

E. STRESS ANALYSIS

The stress analysis of the upper drag brace was performed in two parts, a finite element analysis of the lug area and conventional analysis of all other areas of the brace, including buckling analysis of the complete assembly.

As evidenced by the previously discussed tedious lug area design evaluation, considerable difficulty was experienced in lug development because of the low shear and transverse tension strength of the graphite epoxy material and the required interchangeability of the composite brace with the existing brace. This constraint severely restricted lug area design and prevented efficient design of the composite brace within envelope restrictions.

The final design of the lug consisted of a titanium bushing bonded into the graphite-epoxy composite. Positive margins of safety exist in all elements of the composite with the exception of the bond line, where several negative margins occur. The lug was utlimately designed for complete failure of the bond line.

The detailed stress analysis technique is presented in Appendix B. Finite element analysis utilized the ANSYS computer program for four alternative lug design and stress combinations -- slip-fit and bonded titanium bushing in either tension or compression loading.

In the finite element analysis, two different approaches were used in determining margins of safety. One is based upon the lamina stress within the composite and the other upon the principal or total stress

carried by the composite. Several negative margins of safety exist in the composite under the lamina stress approach if the bond line is assumed to have completely failed. However, using the second approach and the same bond line assumptions, a small negative margin of safety (-2%) exists at only one element, with all others positive. The margins of safety would be identical in both cases if the fiber (lamina) axes coincided with the principal stress axis because the margin of safety (and actual stress) is very sensitive to variations in fiber and stress axis orientation. In the loaded condition, it was felt that the fiber axis and principal stress axis would approach coincidence and thus the margin of safety based on principal stress axis would be more accurate.

The margins of safety in the bond line were calculated from the maximum shear stress in the bond. Allowable peak shear stress is 7,800 psi at room temperature, based on adhesive test data and analysis presented in Appendix A. This bond line data was used in the finite element analysis.

A theoretical fatigue analysis was not performed because of the lack of test data. Available fatigue data for composite materials relates only to lamina arrangements in a single axis (0°). In the drag brace design, stresses are not unidirectional.

F. WEIGHT SUMMARY

The finished upper drag brace weighs 7.51 pounds which includes 1.78 pounds of titanium spacers. The existing titanium brace weighs 8.31 pounds, a difference of 0.80 pound and a potential weight reduction of 9.63%.

SECTION IV

TOOLING AND FABRICATION

A. TOOLING

The fabrication technology for the upper drag brace was based on techniques developed for the previous successful fabrication of the A-37B upper side braces. This procedure utilizes the unidirectional 3501/AS prepreg tape of 0.0052 inch thickness to laminate subcomponents, cure these subcomponents at 350^{o}F. in metal molds, machine the subcomponents, and then bond them together using EA934 adhesive in an assembly fixture. The subcomponents consist of two side links, a shear web, five gussets, and four titanium inserts as shown in Figure 7.

At all times during the drag brace design evolution, its producibility potential was a major constraint. It was, thus, the objective of all tooling to facilitate the fabrication of drag brace subcomponents such that theoretical composite strengths would be attained with the greatest economy of weight and cost. Accordingly, the tooling was designed to provide ease of fabrication as well as satisfy processing controls.

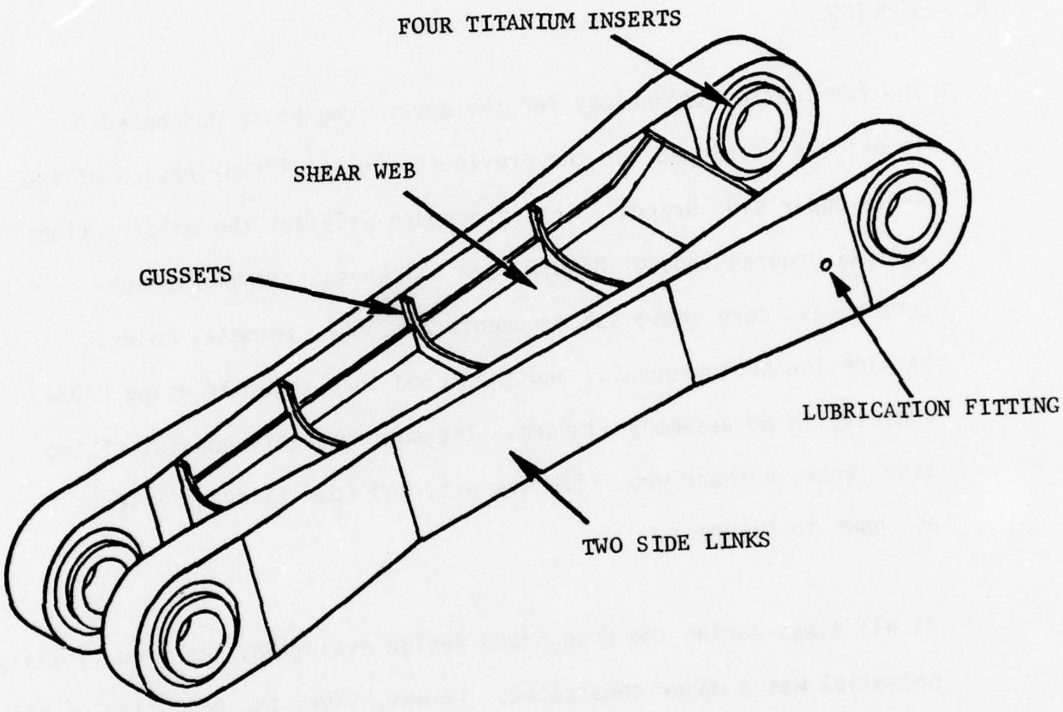


FIGURE 7
F-15 Graphite Composite Drag Brace Assembly

In particular, three of the tools, the side link mold, the titanium insert bond fixture, and the final assembly bond fixture were carefully designed to close tolerances since they controlled final assembly dimensions. The side link mold design also accounted for the difference in coefficients of expansion at the 350^{o}F. cure temperature between the steel mold and the graphite composite.

The tooling designed to satisfy these fabrication requirements is listed below and shown in Figure 8. Its use in the fabrication process is described below and in more detail in Appendix C.

Tool No.	Description	Drawing No.
T-69804	Racetrack Mandrel Set	83008S00771
T-69805	Racetrack Form Tool	83008S00766
T-69807	Main Web Form Tool	83008S00767
T-69809	Racetrack and Web Reinforcement Preform Tool	83008S00769
T-69810	Main Racetrack and Web Preform Tool	83008S00770
T-69811	Side Link Mold Assembly	83008S00764
T-69812	Assembly Bond Fixture	83008S00777
T-69813	Spreader Mold	83008S00773
T-69814	Insert Bond Fixture	83008S00774
T-69815	End Gusset Molds	83008S00775
*	Web Prepreg Cutter	83008S00768
*	Shear Web Prepreg Cutter	SK-CN-001

* Denotes production aid

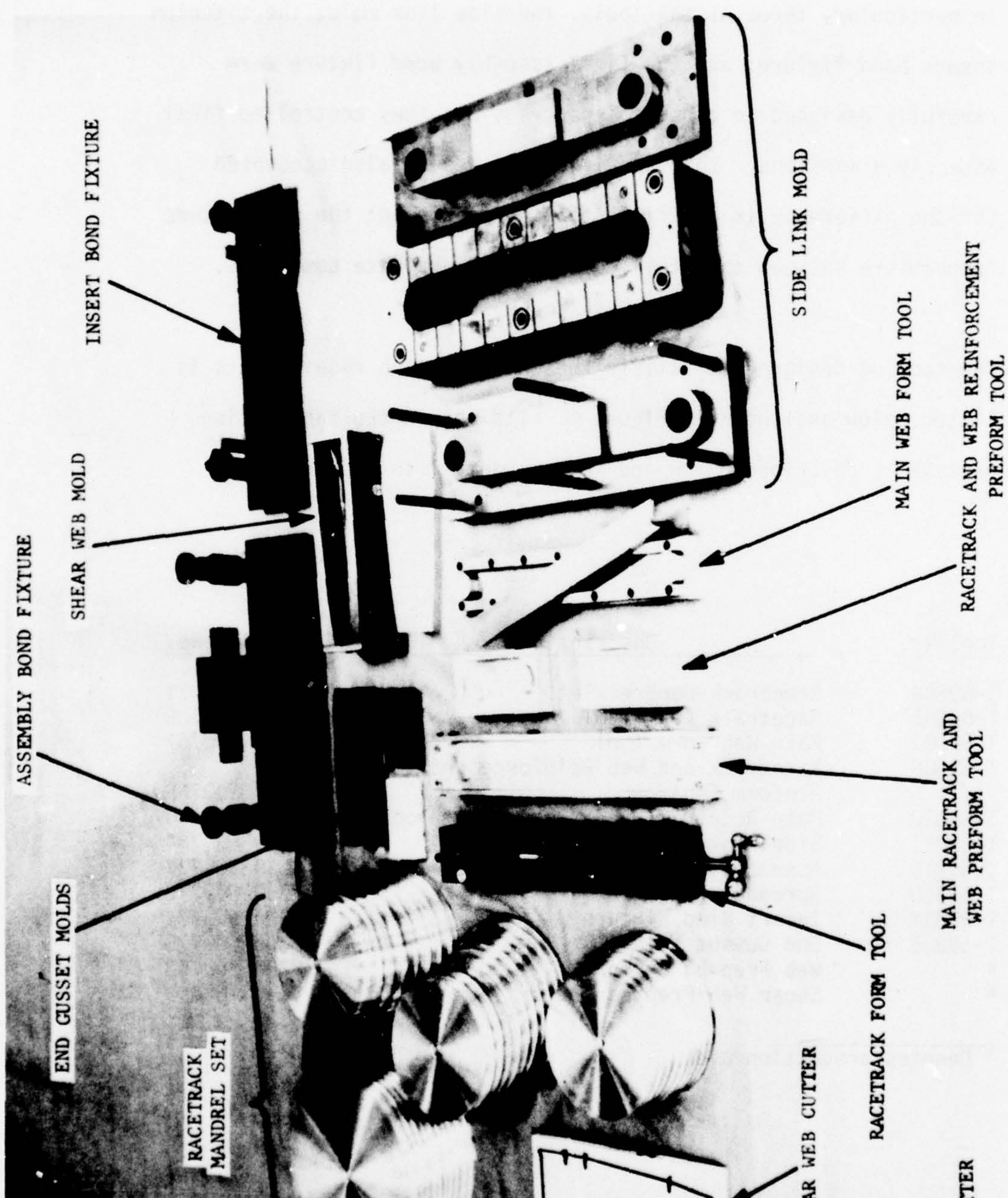


FIGURE 8
Tooling for Graphite Composite F-15 Upper Drag Brace

B. SIDE LINK FABRICATION

The main load-carrying members of the drag brace are the side links. Each was composed of ten components as shown in Figure 9.

Fabrication of fiber laminates begins with the stacking of fiber tape in a predetermined pattern based on the calculated strength of the tape and the laminate. This consists first of the stacking of individual prepreg tapes into layers or "sub-laminates" and then the stacking of these "sub-laminates" into the final shape or laminate. The individual fiber tapes are oriented (0^o, $\pm 45^o$, or 90^o) for overall strength of the layer ("sub-laminate") and the layers are oriented at assembly for overall strength of the laminate.

Side link fabrication began by stacking prepreg tape in a sequence that would yield a layup $\left[(0_3/\pm 45/90)_2\ (0_2/\pm 45/90)\ (0_3/\pm 45/90)_2\right]_S$ for use in the main web. This indicates a basic laminate consisting of two 0_3, one 0_2, and two 0_3 layers, with the individual layers fabricated as detailed in Appendix C. These broadgoods were cut to size by use of a fabrication aid, the Web Prepreg Cutter. This material was then placed in the flat cavity of the Main Web Form Tool (Tool No. T-69807) and cured under heat and pressure.

The various web reinforcements of 0.325, 0.410, and 0.495 inch widths for each end were made in a similar manner except the stacking sequence used was a $\left[(0_3/\pm 45/90)_2\ (0_2\ \pm 45/90)_3\ (0_3/\pm 45/90)_2\right]_S$ layup. These broadgoods were cut by another fabrication aid (Shear Web Prepreg Cutter) bagged, and put into 0^oF. storage until needed.

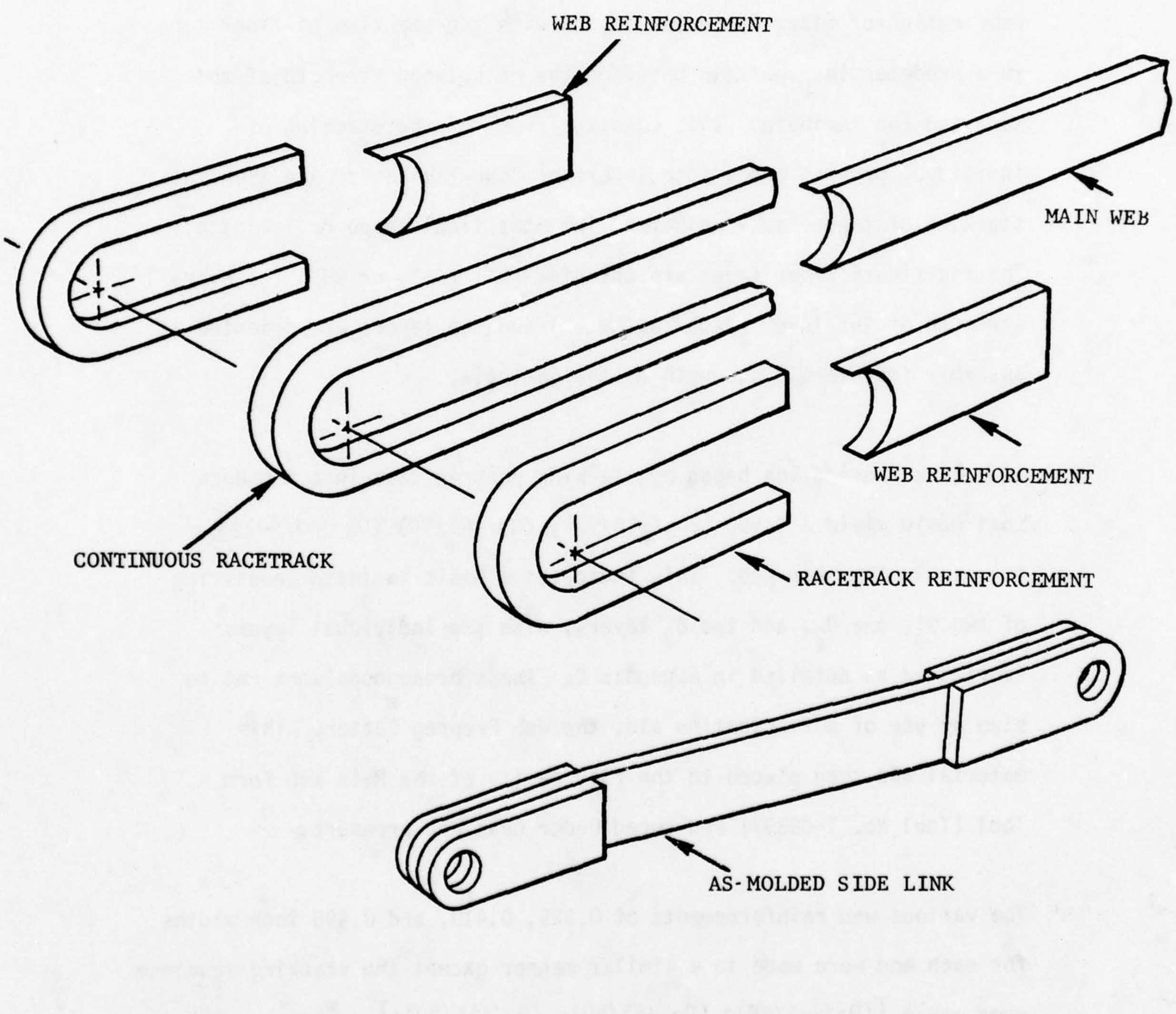
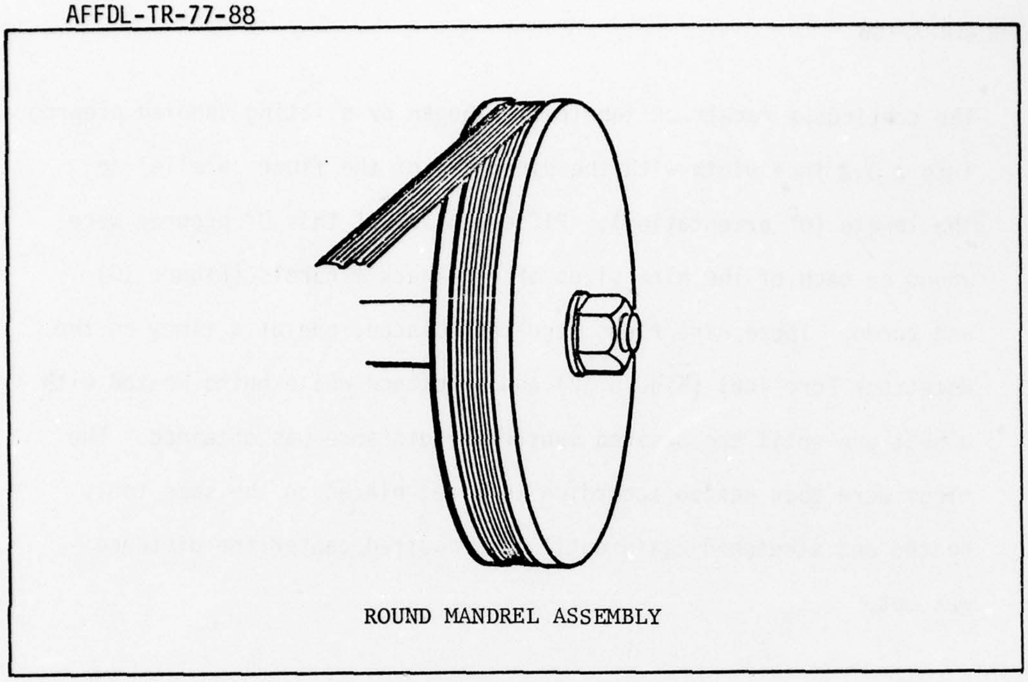


FIGURE 9
Components of Side Link

The continuous racetrack fabrication began by slitting spooled prepreg into a 0.3 inch width with the direction of the fiber parallel to the length (0^o orientation). Fifteen plies of this 0^o prepreg were wound on each of the nine sizes of racetrack mandrels (Figure 10) and cured. These nine rings were then placed, one at a time, on the Racetrack Form Tool (Figure 10) and stretched while being heated with a heat gun until the desired centerline distance was obtained. The rings were then nested according to size, placed on the same tool, heated and stretched again until the required centerline distance was met.

The continuous racetrack was then placed into the Main Racetrack and Web Preform Tool (Tool No. T-69810) along with the main web as shown in Figure 11. Bleeder material was added and a vacuum bag installed prior to undergoing a heat compaction cycle in the autoclave. This last step also formed the bends in the side link.

The 0.325, 0.410, and 0.495 inch wide racetracks for the end reinforcements were formed in a manner similar to the continuous racetracks. They were cut in half and placed into the Racetrack and Web Reinforcement Preform Tool (Tool No. T-69899) with the reinforcement webs (Figure 12). They were then subjected to a bleed compaction cycle similar to that performed on the main web and continuous racetrack.



Racetrack Winding

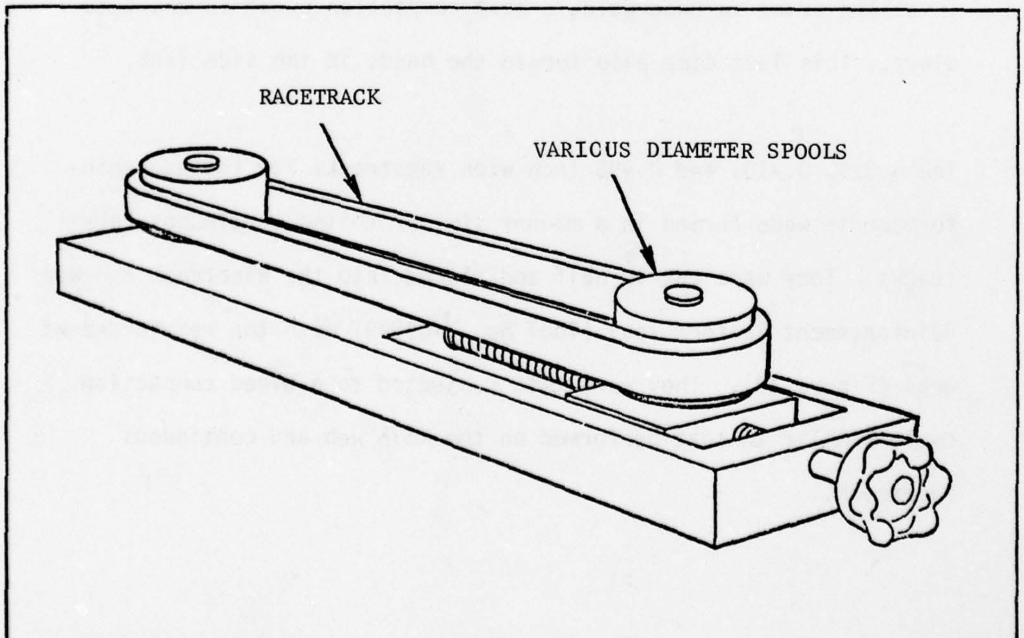


FIGURE 10
Racetrack Form Tool

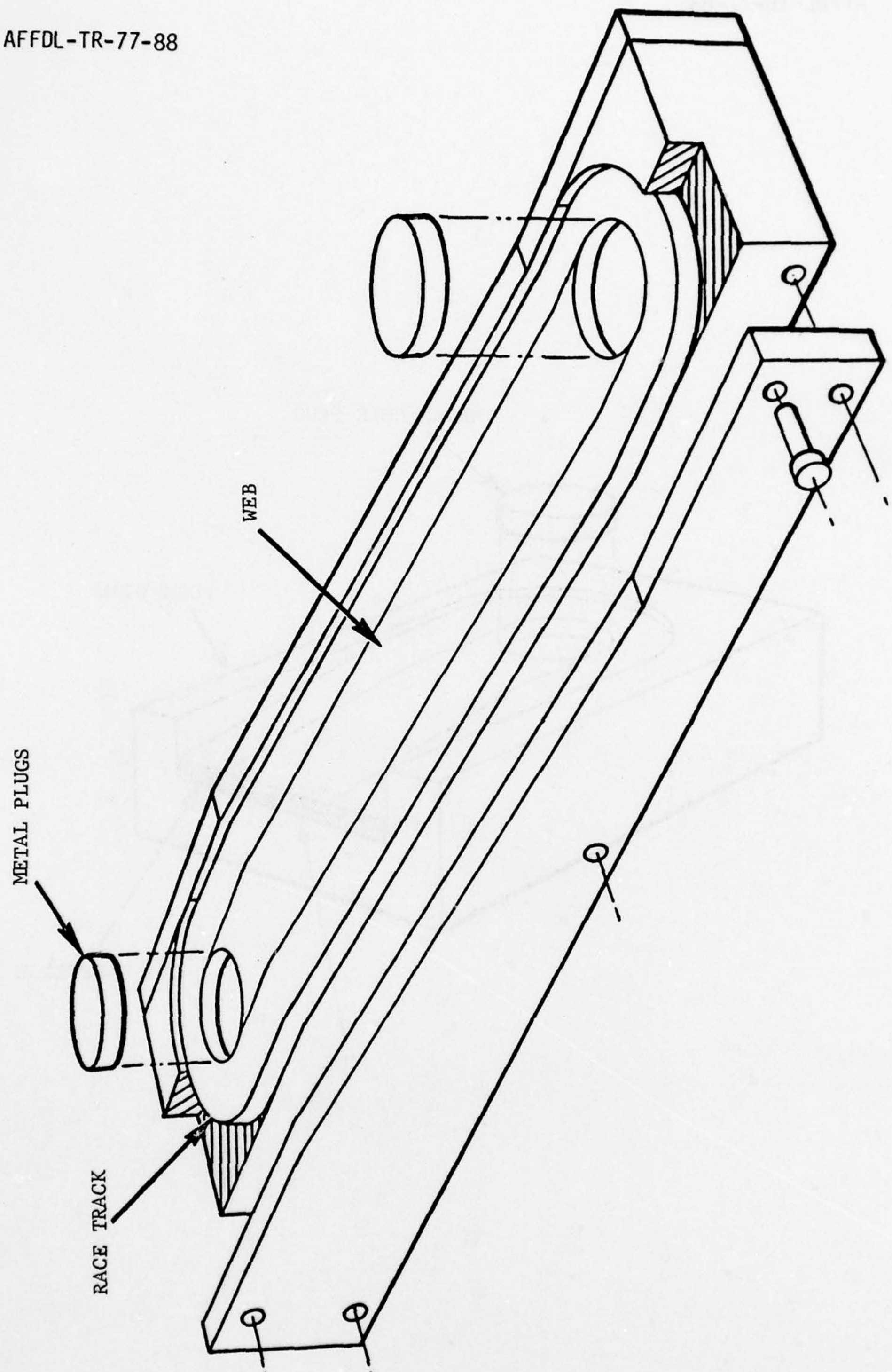


FIGURE 11
Main Racetrack and Web Form Tool

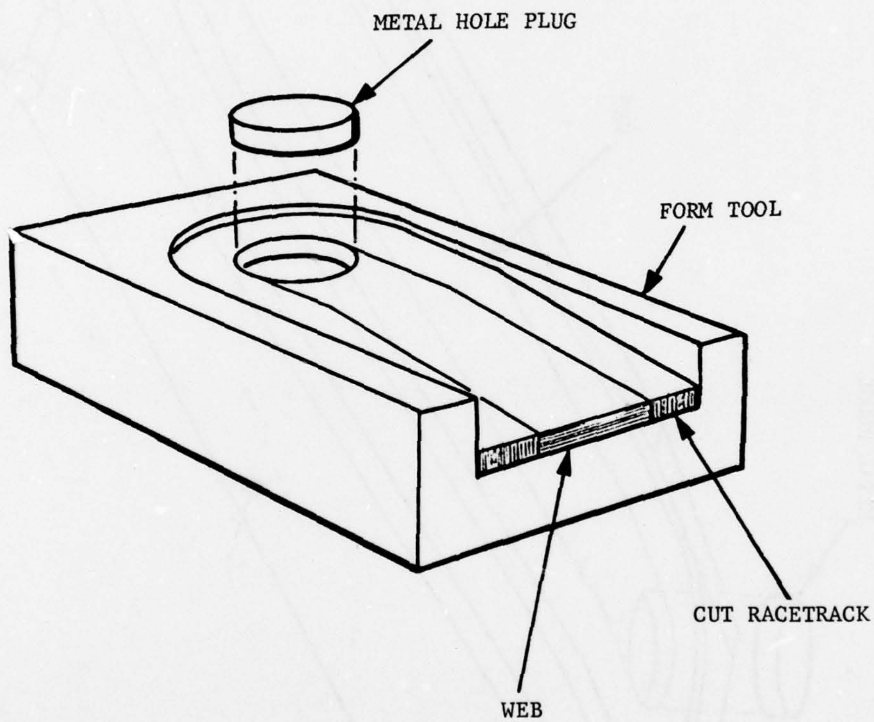


FIGURE 12
Racetrack and Web Reinforcement Preform Tool

Cure of the side link was performed in a Mold Assembly (Tool No. T-69811) presented in Figure 13. The bottom mold plate has six pressed-in-place dowel pins for alignment purposes, two close fitting pins for sizing the side link bores, and a bolted-on-form to shape one side of the link. The mold cavity restrains the side link perimeter and has channels for excess resin venting during compaction. The top mold plate has holes to accept the alignment pins and a bolted-on form to shape the other side of the link.

The mold was loaded by placing the preformed end reinforcements of the proper thicknesses in the end recesses with the mold cavity resting on the bottom plate. The main racetrack/web preform was positioned in the cavity and the remaining end reinforcement preforms placed in the mold cavity. Finally, the top mold plate and thermocouples were installed.

The side link cure cycle took place in a platen press as follows:

1) Place 0.020 thick shims between the top plate and mold cavity
2) Apply 50 tons of load on mold assembly
3) Apply heat until part reaches 250°F. and hold for 1 hour
4) Remove shims, close mold, and maintain pressure
5) Bring part temperature to 300°F. and hold for 1/2 hour
6) Bring part temperature to 350°F. and hold for 1 hour
7) Remove bore pins while mold is at 350°F.
8) Remove part from mold at temperature above 300°F.

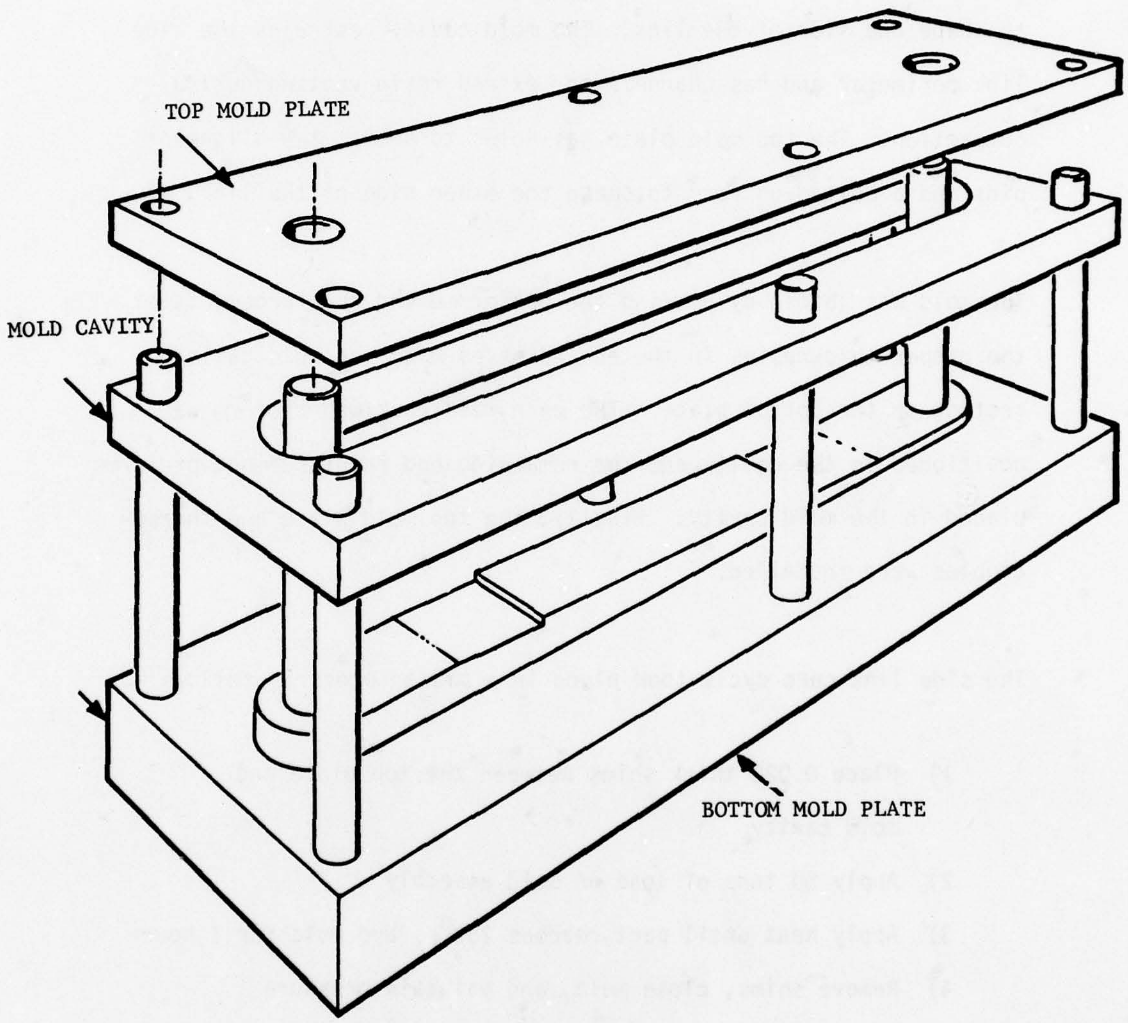


FIGURE 13
Side Link Mold Assembly

After the side link had cooled to room temperature it was visually and dimensionally inspected. Machining of the tapered areas of the end reinforcements and insert bores was accomplished with standard machine tools and practices using water as a coolant.

The end reinforcements were not molded to a taper configuration in order to reduce fabrication time by eliminating the cutting of individual web plies of varying lengths.

C. SHEAR WEB FABRICATION

Prepreg tape was stacked in a $(0_3/\underline{+}45/90)_{2S}$ layup prior to being cut to size with the Shear Web Prepreg Cutter. The prepreg plies were then loaded into the mold arrangement (Tool No. T-69813) as seen in Figure 14. The silicone plug, due to the extremely high coefficient of expansion when heated, compacted the prepreg against the female mold during the cure cycle.

Cure was performed as follows in a platen press:

1) Apply sufficient pressure to close the mold
2) Apply heat until part reaches 250°F. and hold for 1 hour
3) Bring part temperature to 300°F. and hold for 1/2 hour
4) Bring part temperature to 350°F. and hold for 1 hour
5) Remove pressure
6) Disassemble mold while hot

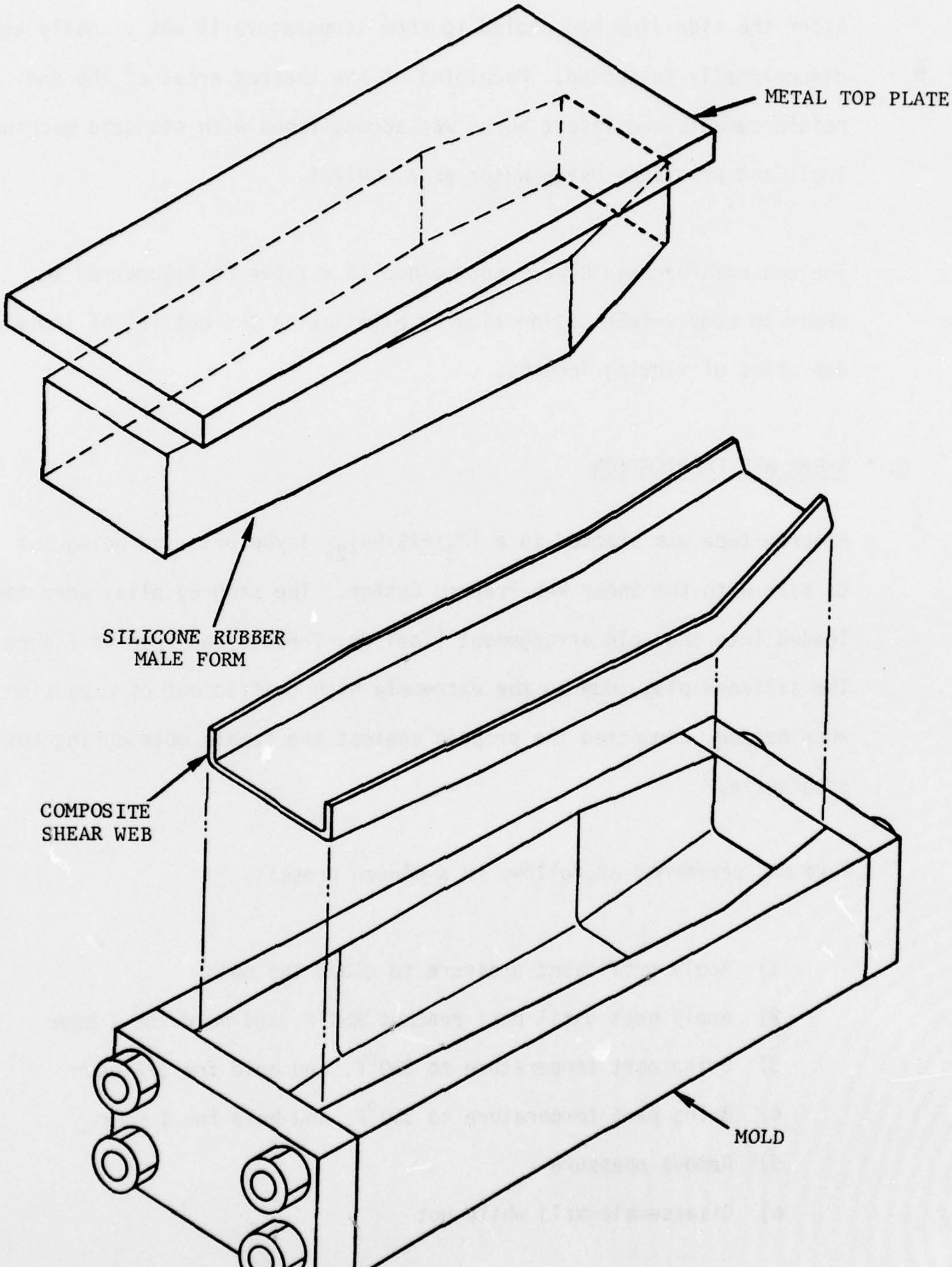


FIGURE 14
Shear Web Cure Mold

After the part had cooled to room temperature, it was visually inspected, machined to length and side height, and dimensionally inspected.

D. U-SHAPED END GUSSETS

Both end gussets were fabricated from cut prepreg with a $(0_3/\underline{+}45/90)_{2S}$ layup using the cure cycle defined for the shear web.

Both the small and large end gussets were formed in molds similar to Figure 14. Both used a silicone plug to compact the composite during cure. Removal of the parts from the molds occurred at room temperature. Machining to length and leg height was then performed.

E. FLAT GUSSETS

Existing tooling was used to cure flat panels (0.12 inch thick) of a $(0_2/\underline{+}45/90)_{3S}$ layup. The following cure cycle was performed:

1) Place mold arrangement in platen press with 0.020 inch thick shims between caul plate and mold stops
2) Apply pressure when prepreg reaches 225°F. until shims are contacted
3) Bring prepreg to 250°F. and hold for 1 hour

4) Remove shims, increase pressure on caul plate until it contacts the mold stops

5) Heat composite at 300^{O}F. for 1/2 hour

6) Heat composite at 350^{O}F. for 1 hour

7) Remove caul plate and identify orientation

8) Remove panel from mold

The cured panels were then inspected and machined to the shape seen in Figure 15.

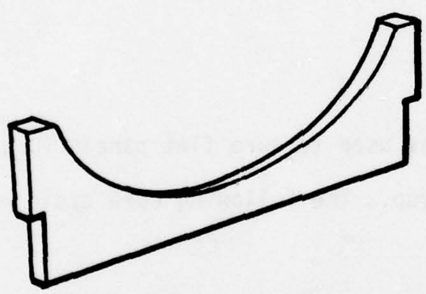


FIGURE 15
Flat Machined Gusset

F. INSERT BONDING

The Insert Bonding Fixture (Tool No. T-69814) arrangement is presented in Figure 16. Prior to surface preparation of the bond areas, a trial fit of the components was made and verified. Bond line wires (0.005 inch diameter) were taped in place in the bores of the composite side link to ensure a minimum bondline thickness. The lubrication hole alignment pin was release-coated to prevent any possibility of bonding it to the side link.

Prior to bonding the titanium inserts into the side links, all bond surfaces were prepared. Insert surface preparation in the bond area consisted of degreasing with methylene chloride, grit blasting with No. 54 grit, degreasing again, drying, performing a Pasa-Jell 107 surface treatment, then drying again. The composite bores of the side links were prepared by degreasing, lightly sanding with 220 grit silicone carbide abrasive paper, degreasing, and then drying. Great care was taken to avoid contamination of the prepared surfaces.

The required amounts of Part A and B of EA934 adhesive were carefully weighed and mixed for a minimum of ten minutes. Bond surfaces of the inserts and side links were coated with excess adhesive and the surfaces worked to ensure wetting. Both inserts were then slipped into the side link. The alignment pin was slipped through the lubrication hole of the side link and wide end insert. This arrangement was placed on the tooling alignment pins and the excess adhesive

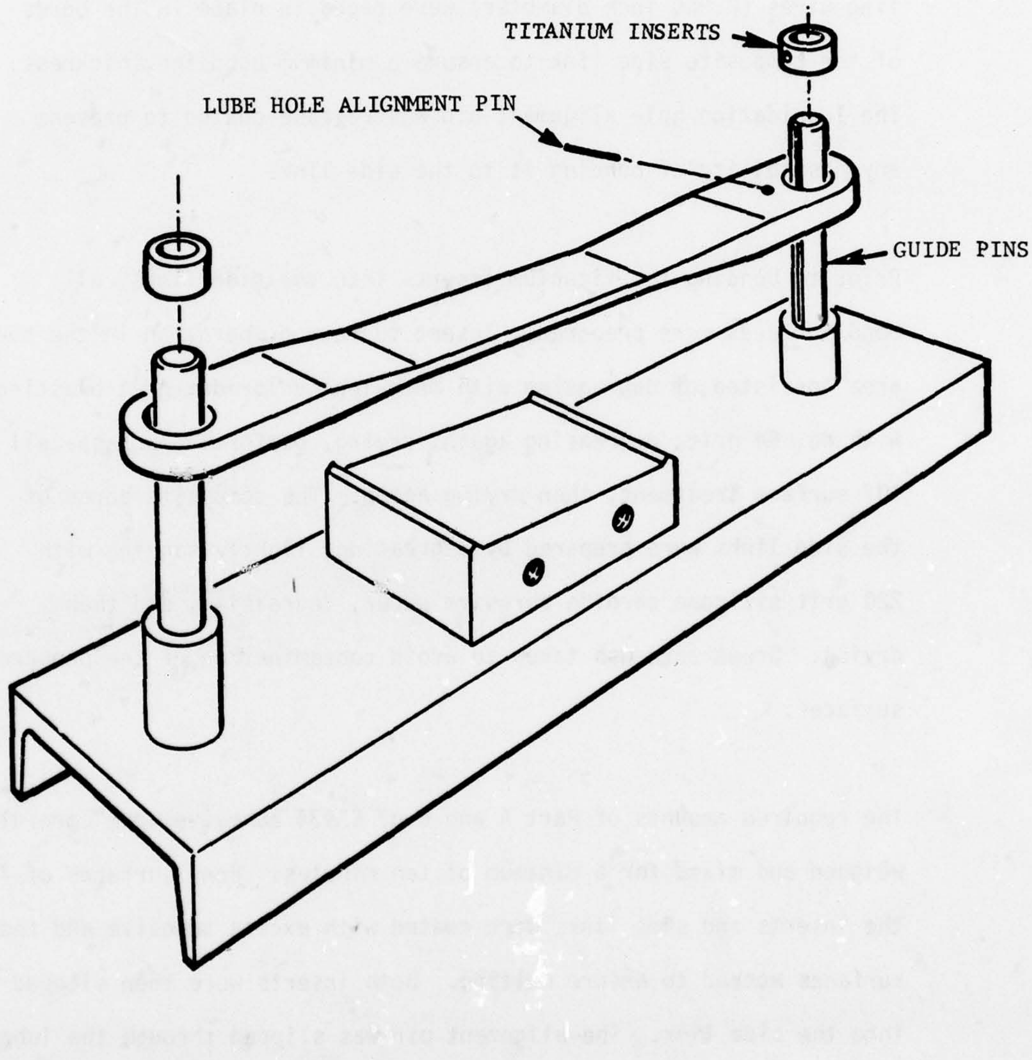


FIGURE 16
Insert Bond Fixture

removed. The part was then clamped in place and remained in the fixture at least 8 hours before removal. Cleanup and removal of the lubrication hole alignment pin occurred after 20 hours in the fixture.

This sequence was repeated for the second side link bond operation. Great care was required during the bond operation to ensure that the correct insert was in the proper hole and that the side link was turned properly.

G. ASSEMBLY BONDING

Bonding of the side links to the shear web was performed in the fixture shown in Figure 17, the Assembly Bond Fixture. Trial fitting was approved before bond operations started. Surface preparation on the composite bond area was performed as previously described. Bondline wires of the proper diameter (determined during trial fit) were located along the side links to ensure a minimum bondline. Gussets were held in place during adhesive set-up with clamps, blocks, etc. Fillets were carefully worked along the bondlines and excessive adhesive removed.

After the adhesive had set up, final cleanup operations were performed prior to dimensional inspection.

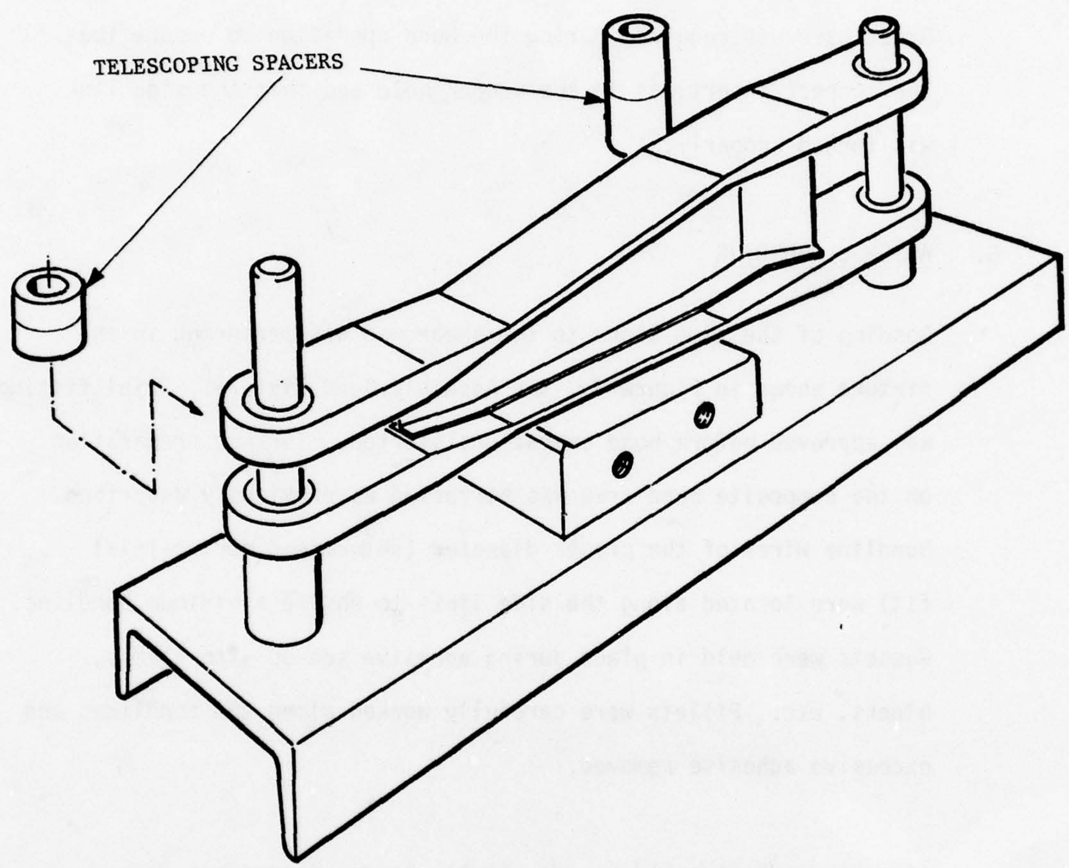


FIGURE 17
Drag Brace Assembly Bond Fixture

H. QUALITY ASSURANCE

The entire fabrication process was monitored by conventional materials accountability and control documents and by materials conformance and process certifications at each intermediate operation.

The 3501/AS prepreg exceeded minimum requirements as demonstrated in the acceptance test. After cooling, all parts were visually and dimensionally inspected, and were again inspected after machining. In addition, the shear web and side links were radiographically inspected before machining, after insert bonding, and after final assembly bonding. The radiographic inspection procedure is presented in Appendix D. In addition, an ultrasonic inspection procedure is presented in Appendix E. At the present time ultrasonic interpretation techniques are inadequate for detailed composite inspection and, likewise, x-ray/ultrasonic correlation data has not been established. As a result, the in-process ultrasonic inspection procedures were not used for quality assurance.

The composite drag brace was slightly oversize at several locations, probably the result of mold closure technique during cure of the side links. In addition, radiographic inspection of the side links revealed a fiber waviness condition in the cured continuous racetrack at the inside ends of the side reinforcements. These deficiencies appeared to be within normal fabrication tolerances and the parts were released for testing.

SECTION V
TESTING AND TEST RESULTS

A. TEST PLAN

Following fabrication and all in-process quality assurance procedures, the brace was assembled in the test fixture (Figure 18) as a component of the complete F-15 drag assembly. The complete qualification test program was to consist of:

- Initial proof test to a tension load of 102,400 lbs (2/3 of design static load).
- Fatigue test of six lifetimes as defined in the F-15 Fatigue Spectrum of the Test Plan.
- Static load tests of 153,600 lbs tension and 156,300 lbs compression.

A complete description of test set-up and procedures and success criteria are presented in the Test Plan, Appendix F. The upper drag brace was thoroughly strain gaged with strain data recorded, to derive verification of loads and stress values. Strain gage locations are shown in Figure 19.

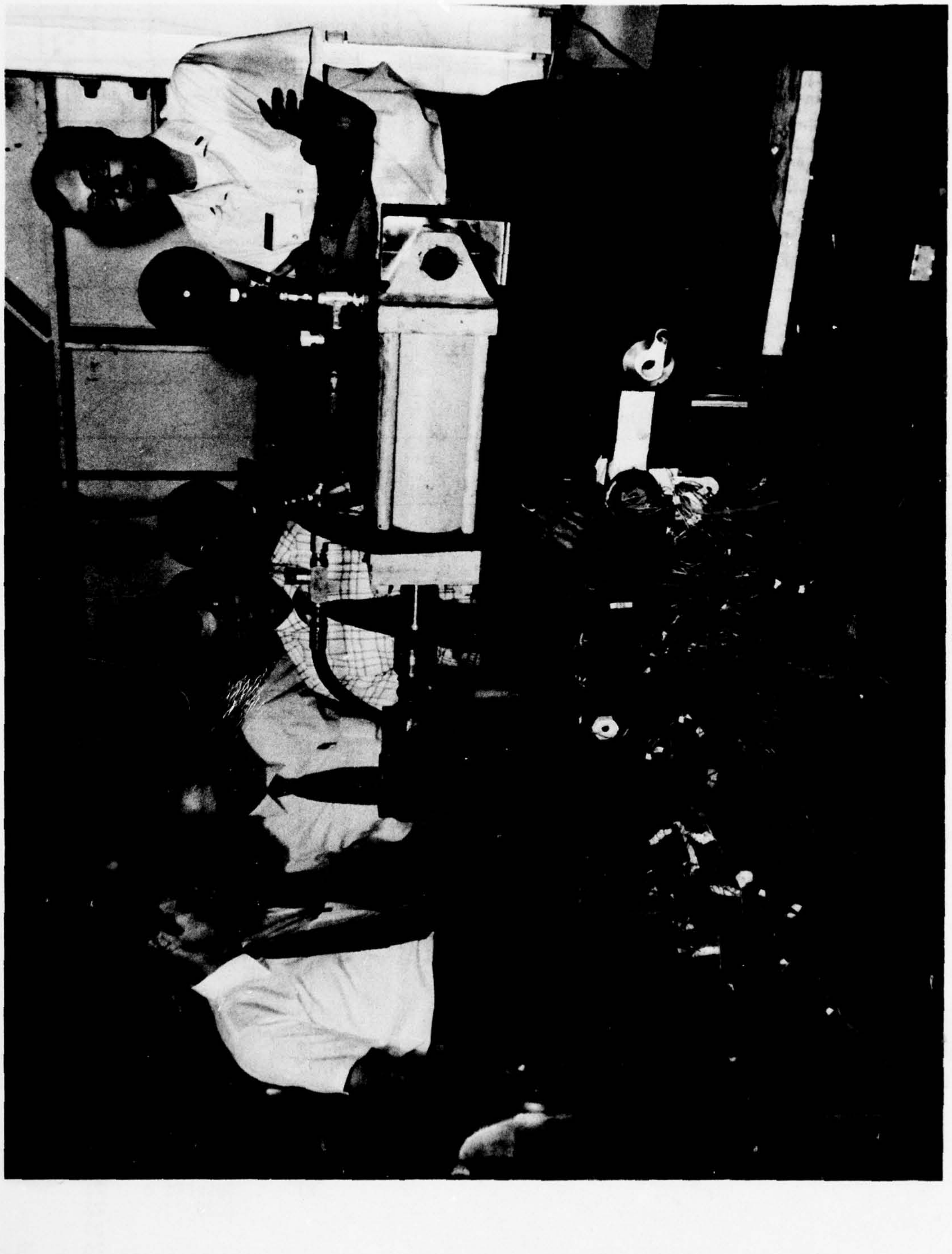
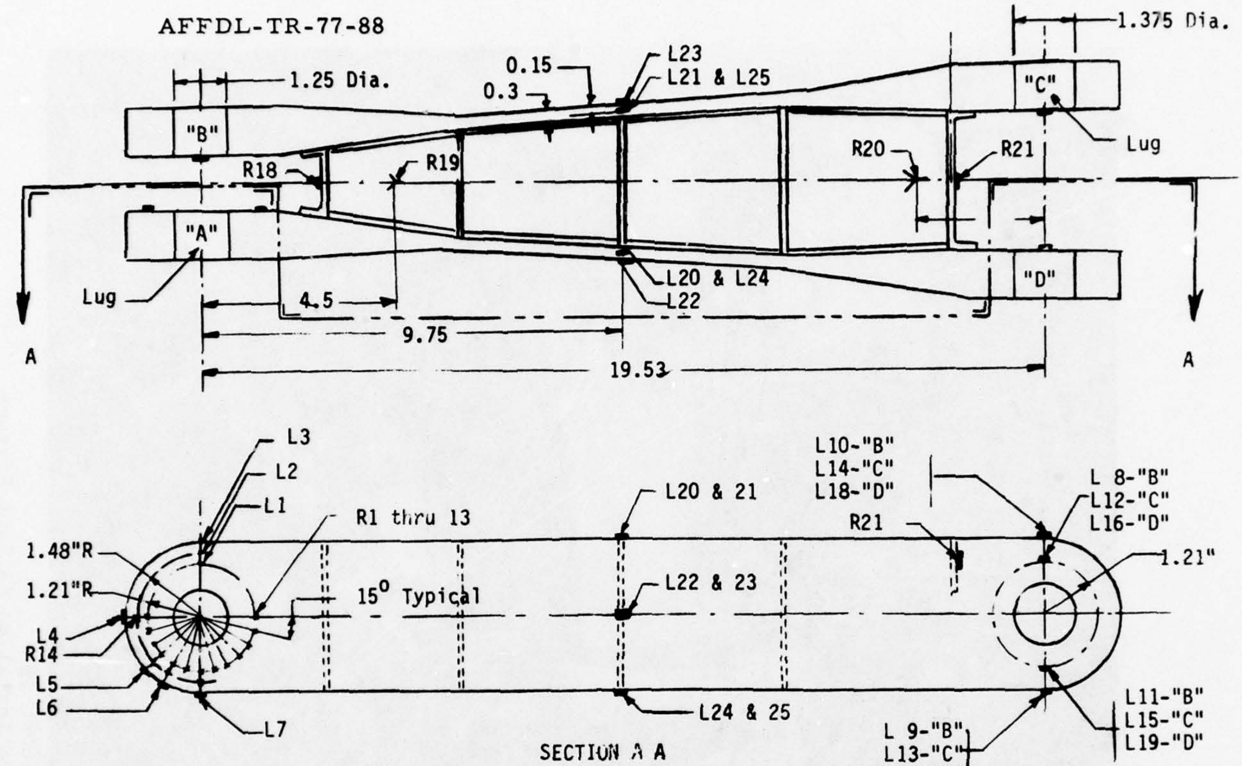
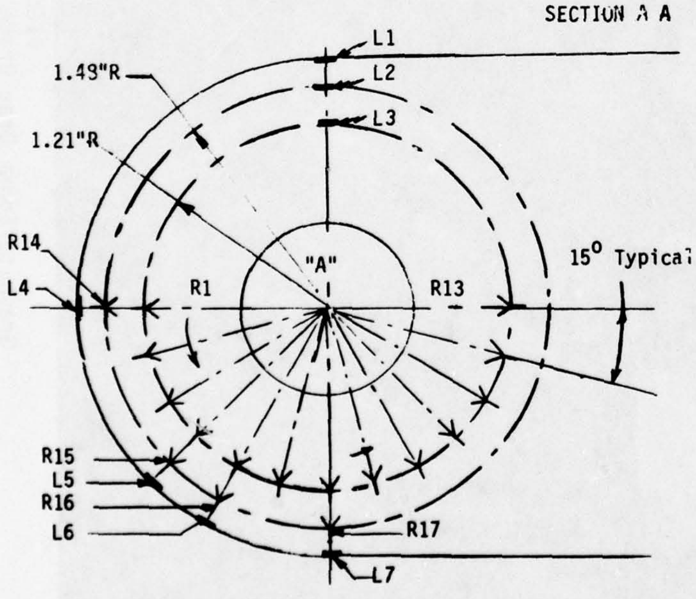


FIGURE 18
Graphite/Epoxy Drag Brace Installed in Test Fixture





Gage No. (Rosettes)	Location	Gage No. (Linear)	Location
R 1	Lug A at 1.21R	L 1	Lug A 1.21R
2		2	1.48R
3		3	1.75R
4		4	1.75R
5		5	1.75R
6		6	1.75R
7		7	Lug A 1.75R
8		8	Lug B 1.21R
9		9	1.21R
10		10	1.75R
11		11	Lug B 1.75R
12		12	Lug C 1.21R
13		13	1.21R
14	Lug A at 1.48R	14	1.75R
15		15	Lug C 1.75R
16		16	Lug D 1.21R
17		17	1.21R
18	Gussett @ 2.85	18	Lug D 1.75R
19	Web @ 4.50	19	Lug D 1.75R
20	Web @ 3.00	20	Mid-Section 1.75R
21	Gussett @ 2.16	21	
		22	
		23	
		24	Mid-Section
		25	

FIGURE 19

Strain Gage Locations

B. TEST RESULTS

The upper drag brace was assembled in the test fixture. Loads were being applied to calibrate the strain gages when the tension failure shown in Figure 20 occurred at a location on the brace approximately six inches from the small clevis end. The unit had been loaded to 20,000 lbs tension and unloaded for calibration. It was being loaded to 30,000 lbs tension when the failure occurred. Maximum strain values at gage locations are listed in Table 3. Analysis of Strain Gages Nos. L20 through L25 indicated severely asymmetrical strain (stress) loading across the brace at failure. This is shown in Figure 21, which illustrates that strain on one side of the brace was more than twice that on the other side. Total load in the brace at failure was approximately 30,000 lbs tension.

In an effort to determine if the test failure was an isolated case, the first upper drag brace, i.e., the tool trial unit, was ultrasonically inspected for subsequent testing in the test fixture. To date, neither ultrasonic interpretation standards nor ultrasonic/radiographic correlation techniques have been developed for composite structures. Accordingly, the ultrasonic data was of no value in predicting unit integrity.

This tool trial unit was installed in the test fixture and strain gages were attached in the area of failure of the previously tested unit. The tool trial unit was loaded to approximately 7,500 lbs tension when testing was stopped after several loud "pops" were heard and a crack was found in the same area as the failure point of the original test unit.

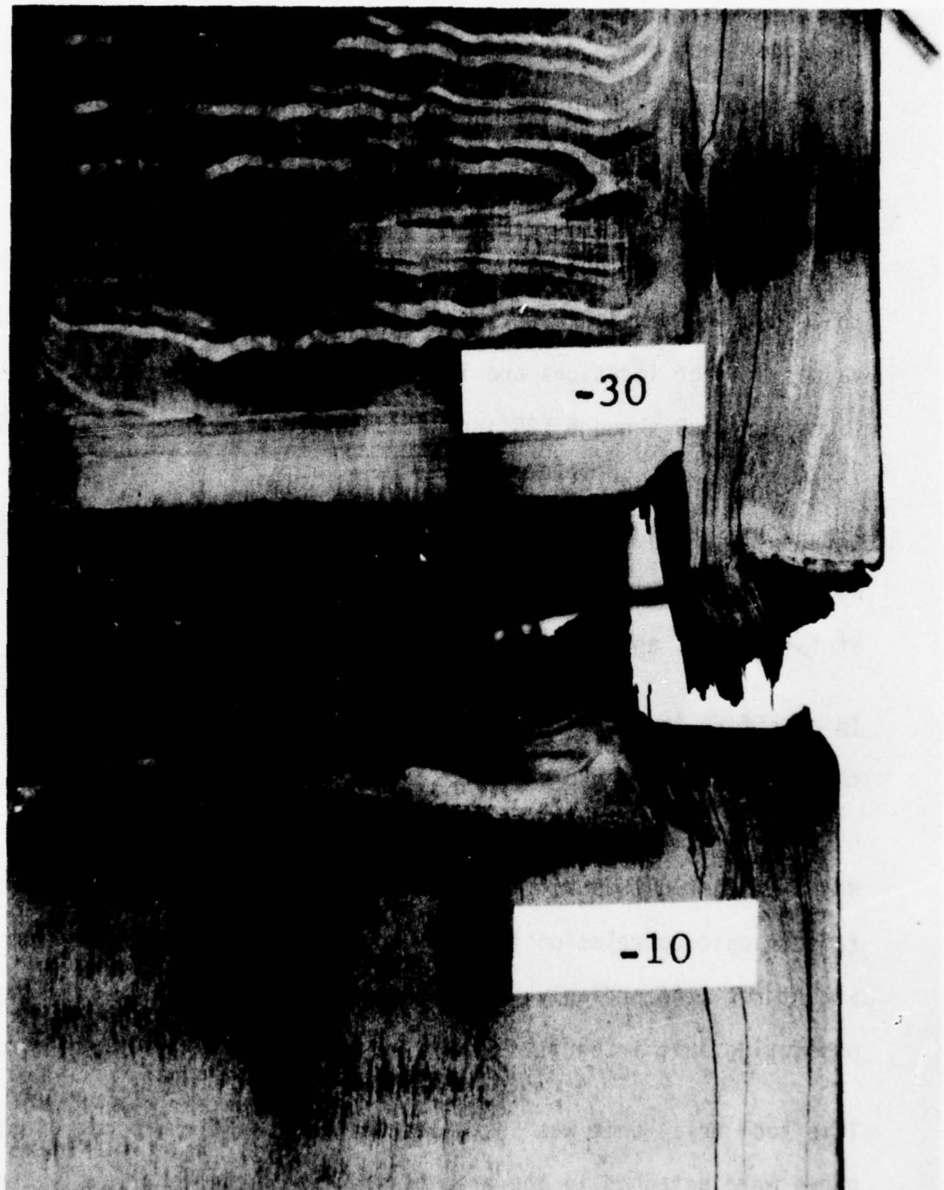


FIGURE 20
Side Link Racetrack Fiber Displacement

TABLE 3
DISTRIBUTION OF STRAIN WITH TENSION LOAD

Strain Gage Number	Maximum Strain Values Tests One Thru Five	
	Load 10,142 lbs. (6.6% of Design)	Load 20,152 lbs. (13% of Design)
	Micro Strain Inches/Inch	Micro Strain Inches/Inch
L1	192	492
L2	120	344
L3	40	224
L4	156	360
L5	132	340
L6	176	388
L7	48	156
L20	368	736
L21	388	768
L22	368	840
L23	1,080	1,960
L24	--	776
L25	--	1,492
R1-1	-660	-1,196
R1-2	-44	-92
R1-3	24	176
R2-1	-572	-1,069
R2-2	-100	-100
R2-3	120	272
R3-1	-520	-992
R3-2	-136	-124
R3-3	172	336
R4-1	-456	-944
R4-2	-276	-348
R4-3	320	572
R5-1	-348	-812
R5-2	-196	-236
R5-3	368	684
R14-1	-360	-648
R14-2	20	80
R14-3	84	224
R15-1	-296	-584
R15-2	-124	-148
R15-3	204	372
R16-1	-280	-552
R16-2	-176	-216
R16-3	260	516
R18-1	--	-344

NOTE: Positive strain values indicate tension.
Negative strain values indicate compression.

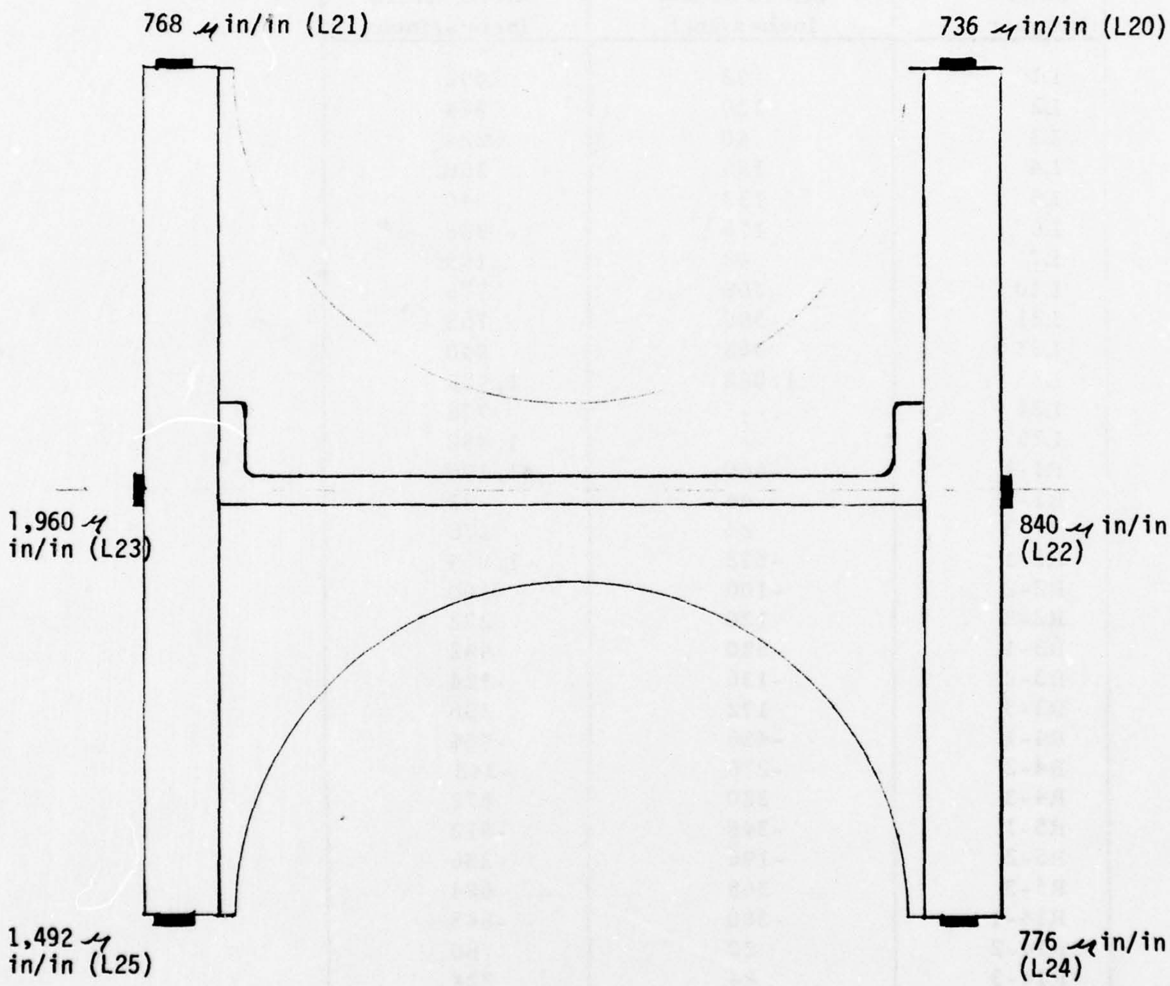


FIGURE 21
Strain (Stress) in Drag Brace at Failure

SECTION VI
FAILURE ANALYSIS

The failure of the brace at a load of approximately 30,000 lbs, much less than the design load of 153,600 lbs, caused a review of the design and fabrication techniques for the composite brace.

A. DESIGN

The design of the graphite epoxy composite upper drag brace was performed using the finite element theory of stress analysis and incorporating precise prepreg physical properties determined by laboratory test data. In addition, these computational techniques were further confirmed for a similar application by the successful design of the A-37B landing gear components.

B. FABRICATION

A non-destructive examination of the composite upper drag brace was performed on the unit that had completely parted under the applied tension load. Based on this examination, it is concluded that racetrack fiber alignment discrepancies and resulting cut fibers were the main cause of failure.

Fiber alignment discrepancies in the racetrack are believed to have been caused by two separate factors. First, the procedure of

generating the racetrack as nine individual racetracks wound, expanded, and nested, and then mated to a web for curing in a match metal mold tends to result in excess length material. In the curing/molding operation, any excess length then leads to fiber misalignment. Second, the side link was molded as a complete unit -- racetrack, web, end reinforcements -- and there is evidence that fiber misalignment in the racetrack resulted from the end reinforcement being pressed into the racetrack. It further appears that many of the resulting misaligned racetrack fibers were subsequently machined away when the reinforcement taper was machined.

Specific fabrication procedures which contributed to the fiber alignment discrepancies are:

1. Racetrack winding procedure

   a) Winding the racetrack onto mandrels instead of directly onto the staged web

   b) Lack of controlled winding tension where the tension increases as the winding progresses

   c) Lack of mechanical compaction as the winding progresses

2. Complete unit molding

   The racetrack fiber alignment problems caused by the end reinforcement being pressed into the racetrack could have been eliminated by curing and bonding end reinforcements to a completely cured racetrack/web assembly.

The racetrack fiber alignment discrepancies caused by the fabrication techniques resulted in premature failure of the composite upper drag brace.

SECTION VII
PRODUCTION COST ESTIMATE

A production cost estimate for an acceptable composite upper drag brace has been prepared based on an analysis of the procedures used for fabrication of the test brace and identification of those design, tooling, and fabrication modifications which would probably be required prior to final acceptance of a production model. Because of the many uncertainties which remain in the program, this cost estimate, based on a 200 piece production run, can best be defined as an order of magnitude value. This estimate is compared below with the existing titanium brace.

	Unit Price (1977 $)
Titanium Brace	$ 1,200
Composite Brace	$ 5,000 - $6,700

The basic composite unit cost is 4 to 5.5 times greater than the current brace and, since tooling cost is not included, an additional cost factor of at least 10% would be required in composite brace pricing.

SECTION VIII

CONCLUSIONS

It must be recognized that this program included severe restraints to the application of new technology. Specifically, these consisted of the requirements to satisfy space envelope size and shape limitations, and to provide complete interchangeability of the graphite/epoxy side brace with the existing production mating hardware. These restrictions combined to cause compromises in the design and fabrication of the graphite/epoxy side brace and the necessity of applying this composite materials technology well beyond the current state of the art. Nevertheless, the following can be concluded from this program.

1. With proper preparation and care during fabrication, titanium inserts can be successfully bonded to a composite structure such as the graphite/epoxy resin combination used in this program.

2. The incorporation of lubrication openings in the composite material was successfully demonstrated.

3. As a result of the aforementioned constraints, and based on the use of current limited fabrication and non-destructive test techniques, this program demonstrated:

   a) Use of existing fabrication procedures results in severe distortions and deformation of the fiber filaments.
   b) Production costs would be higher due to the complexity of composite parts and filament orientation requirements.

It has been estimated that an initial production run of 200 units would cost four to five times more than the current titanium brace.

c) Weight savings were minimal. The total weight of the graphite/epoxy unit with the loading spacers was 7.51 pounds compared to the weight of the existing titanium unit of 8.31 pounds, or approximately 10% reduction.

d) Existing non-destructive inspection techniques are not adequate for a fully acceptable evaluation of complex graphite/epoxy composite hardware.

e) Therefore, the composite graphite/epoxy unit is neither weight nor cost-effective at this time when compared with the present titanium production brace.

SECTION IX

RECOMMENDATIONS

The following recommendations are based on the results of the previously described graphite/epoxy composite materials application program.

1. Continue to monitor:

   a) Advances in analytical, fabrication and non-destructive inspection techniques which result in improved component characteristics and reduced production cost.

   b) Progress in the basic characteristics of fibers and resins. This should include such considerations as the strength, elongation, cost and curing requirements. Emphasis should be given to work aimed at improving the allowable shear stress for graphite/epoxy materials.

2. Develop more definitive non-destructive test techniques to determine the significance of fiber filament shifting and wrinkling, prior to load testing of the specimen.

3. Develop improved, simple and rapid analytical techniques for the design and evaluation of composite materials.

4. The present program should be concluded at this time, in the best interests of the government.

5. Based on the current rapid increase of composite material technology, initiation of a similar program should be evaluated because of the significant cost and weight improvement potential for fabrication of landing gear hardware from composite materials.

APPENDIX A

HYSOL EA 934 ADHESIVE SHEAR STRENGTH

The design allowable shear stress for the bonding adhesive is derived from laboratory overlay tests and conventional probability factors for normal distribution.

Normal distribution theory utilizes an "A" or a "B" basis which relates to the level of probability of surviving a particular occurrence. The "A" mechanical property value is the value above which at least 99% of the population of values is expected to fall, with a confidence of 95%. The "B" value is identical except for an occurrence probability of 90% instead of 99%, thus the "A" value is a more conservative or more positive assumption and is used in the determination of adhesive shear strength.

The "A" allowable stress is determined from the formula:

$$F_A = \overline{X} - K_A S$$

where: $\overline{X}$ = average stress - $\frac{1}{N} \sum_{i=1}^{N} x_i$

$$S^2 = \frac{\sum_{i=1}^{N} (X_i - \overline{X})^2}{N - 1}$$

N = Number of tests

S = Normal variance

K_A = the tolerance factor, on an "A" or "B" basis, derived as a function of the number of tests, N, in Figure A-1.

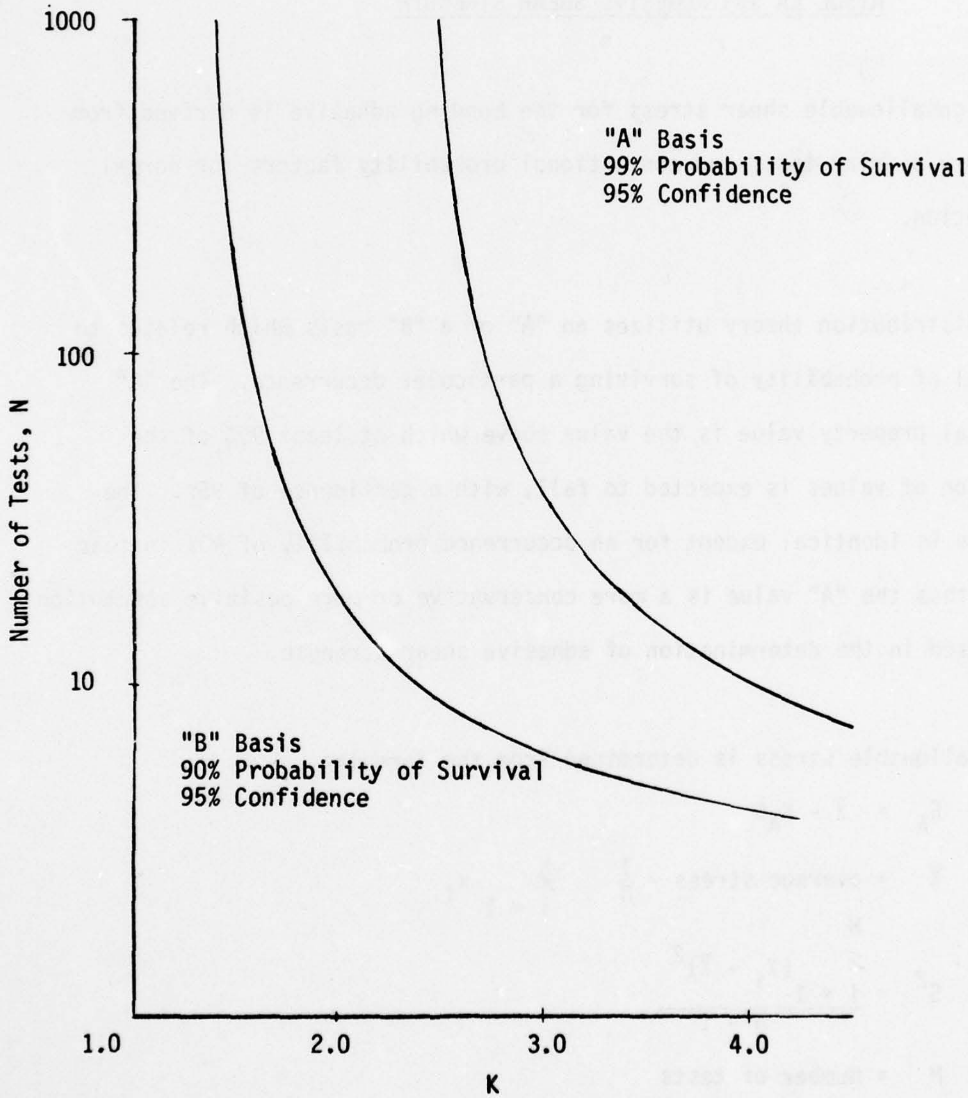


FIGURE A-1
One-Sided Tolerance Factors for Normal Distributions, K

Basic strength data is derived from laboratory lap tests of samples of varying thicknesses and at a wide range of temperatures. The test data from one particular overlay specimen is tabulated in Table A-1. These data are then plotted for various specimens to develop the average shear strength curve shown in Figure A-2. The shear stress peaking factor, K_p, the ratio of peak stress to average stress, is then determined for various bond line thicknesses using the developed finite element program. These values are shown and plotted on Figure A-3.

In designing the adhesive bond line, the peak allowable shear stress was used. For a specific temperature, the peak allowable shear stress may be determined from:

$$\tau_{p_{all}} = K_p \left[\bar{X}\ (1-K_A C_V)\right]$$

From Table A-1, a total of 25 tests (N) were run, with an average shear stress of 3,070 psi. Also, C_V = 8.0%.

From Figure A-1, with N = 25 tests, K_A = 3.15.

From Figure A-3, the shear stress peaking factor, K_p, approaches 3.4 as a minimum.

Therefore:

$$\tau_{p_{all}} = 3.4\ \left[\bar{X}\ \ (1\ 3.15 \times 0.08)\right]$$

$$= 2.54\ \bar{X} \text{ or,}$$

Peak allowable shear stress

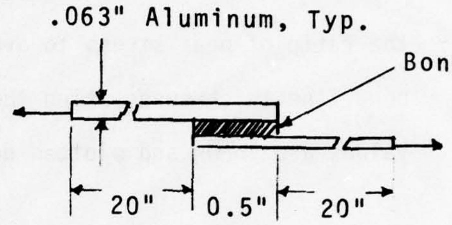
= 7,800 psi at room temperature.

TABLE A-1

RECENT TEST DATA FOR HYSOL EA 934 ADHESIVE

SPECIMEN (See Sketch)

- Single overlap of aluminum to aluminum -- lap length = .5 in.
- Bond thickness -- 1-3 mils
- Sample width = 1.0 in.
- Aluminum thickness = .063 in.



Test Overlay

CURE

7 days at room temperature under 25 psi

DATA MEASURED

- Tensile lap shear strength
- Shear modulus -- no
- Tensile strength -- no

TEST RESULTS (Room Temperature)

Average* Shear Stress, psi	Average* Shear Stress, psi
2905	3310
2920	3095
2890	2980
2970	2750
3014	3450
3070	2860
2870	3820
3050	3200
2830	2980
3010	2840
3310	2960
3210	3010
	3460

$N = 25$

$\overline{X} = 3{,}070$ psi

$S = 24.5$ psi

$C_V = S/\overline{X} = 8.0\%$

* Each data point is the average of 6 tests.

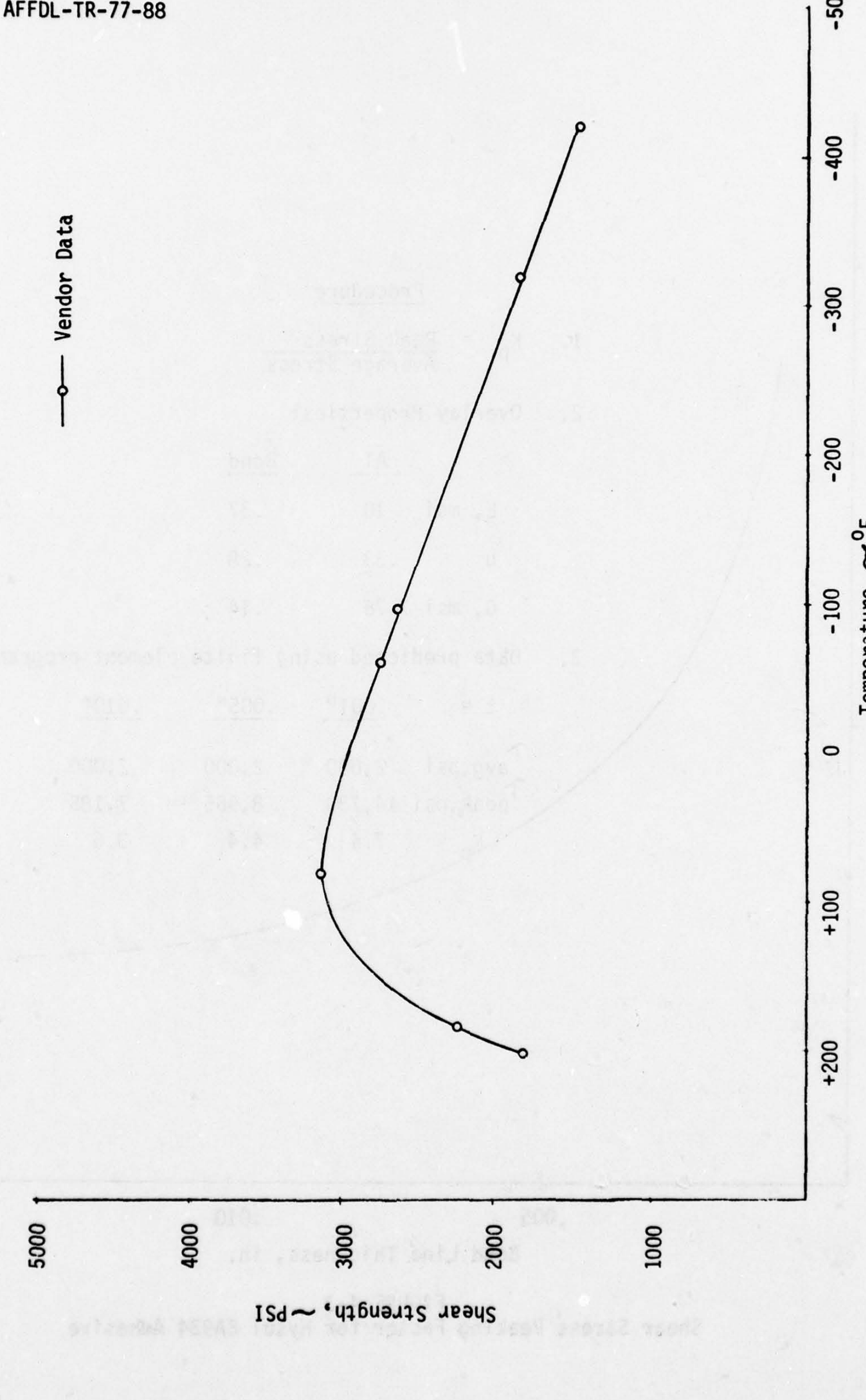


FIGURE A-2
Average Shear Strength Versus Temperature for Hysol EA934

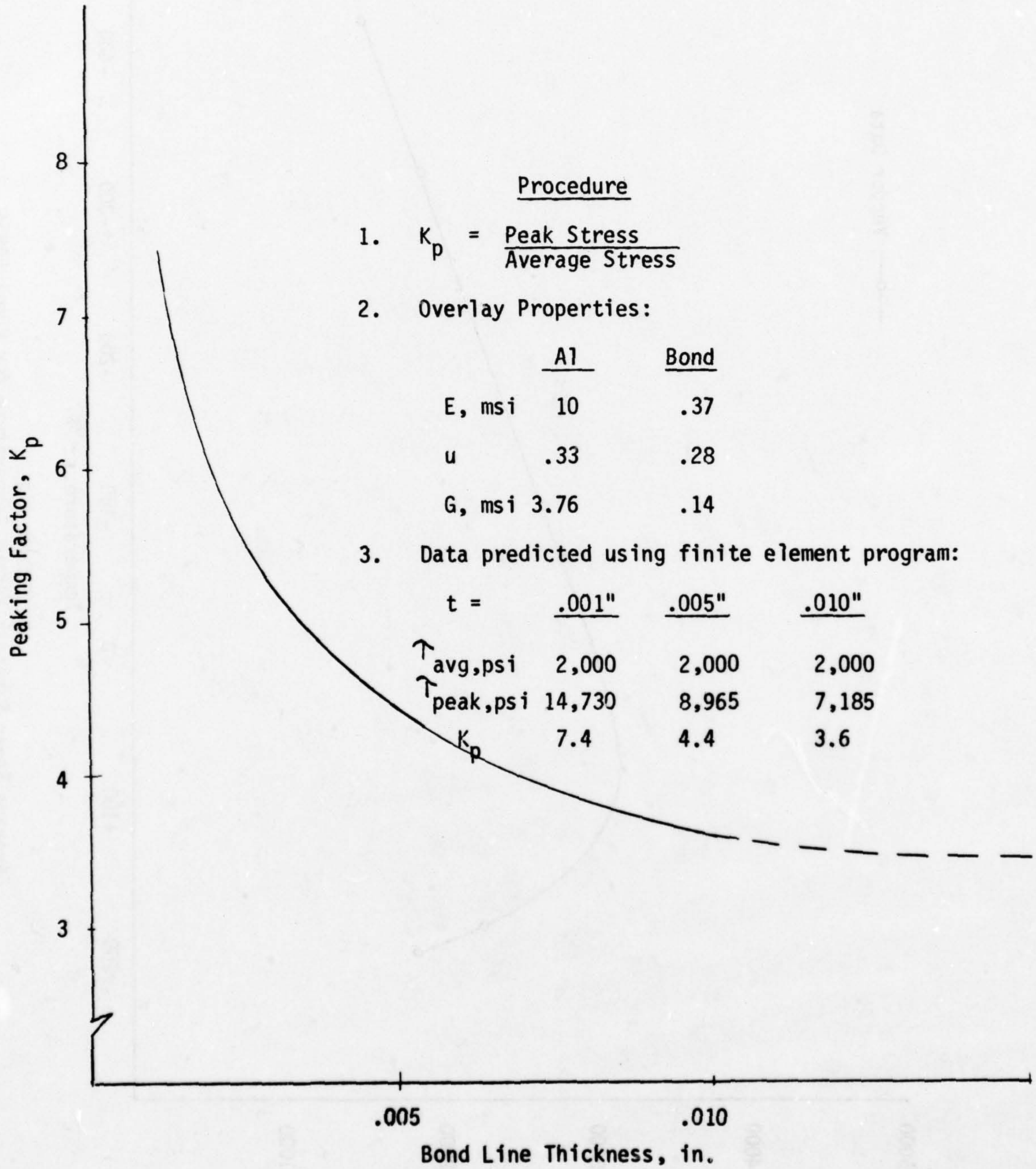


FIGURE A-3
Shear Stress Peaking Factor for Hysol EA934 Adhesive

The calculated peak allowable shear stress over the complete temperature range may then be plotted, as in Figure A-4, to illustrate the adhesive shear strength throughout the entire range.

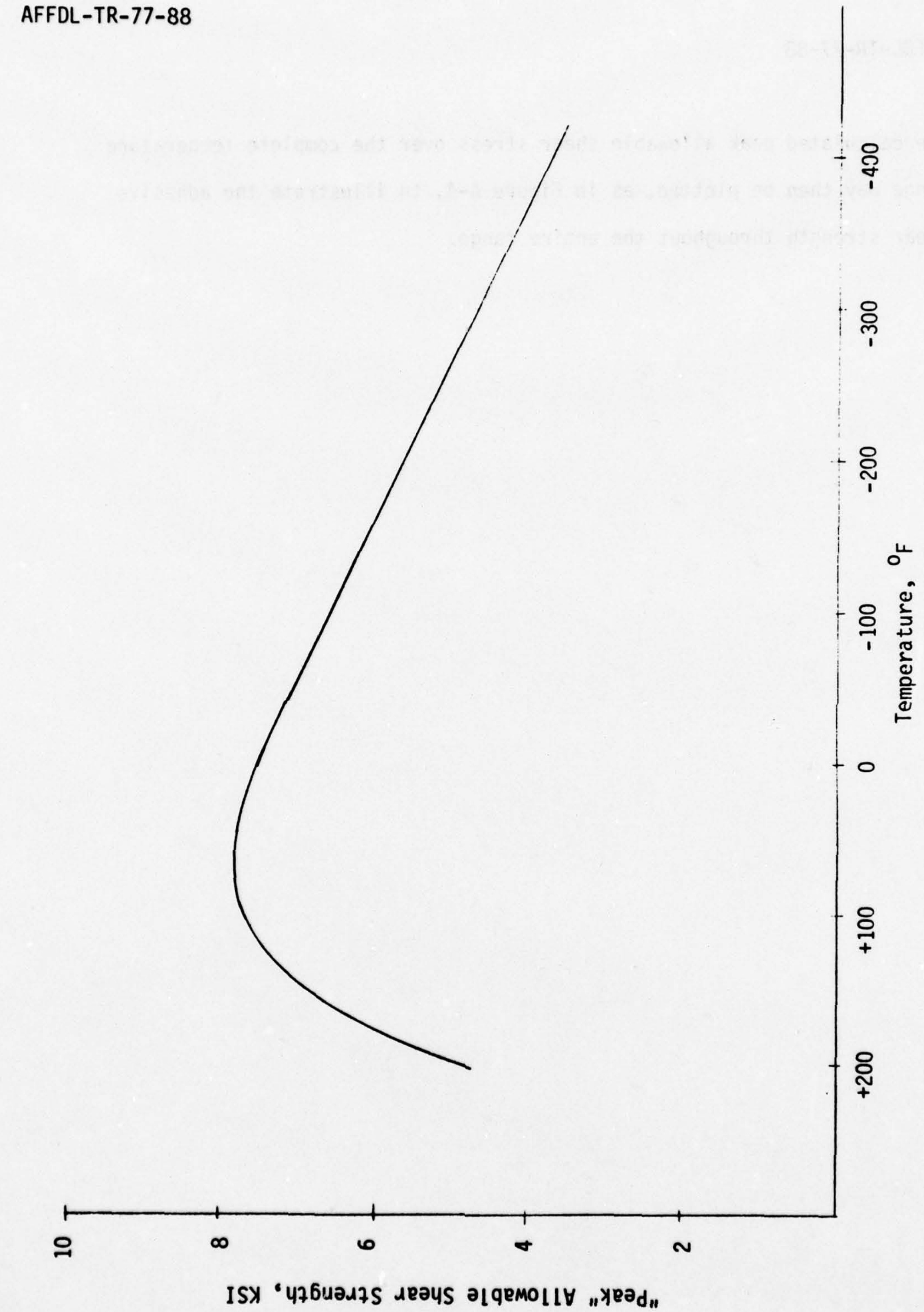


FIGURE A-4
Predicted Peak Shear Strength
("A" Allowables) for Hysol EA934 Adhesive

APPENDIX B

COMPOSITE UPPER DRAG BRACE

STRESS ANALYSIS

The mechanics of composites, like the mechanics of metals, is concerned with the stress and strain distributions in a body which is subjected to external loads. The stress and strain distributions are then used to determine the strength and deflection of the structural members. For convenience, the mechanics of composites can be divided into two basic categories, micro- and macromechanics.

The micromechanics of fiber-reinforced composites is concerned with the stress-strain interrelation of the matrix and fibers, and the interface region between the fiber and matrix. The computational approach is based on the concept of a heterogeneous material consisting of a matrix and a reinforcement. No effective micromechanical approaches have been developed for the analysis of composites, thus, at the present time, macromechanics is exclusively used.

The macromechanical approach ignores the properties of the constituent materials, the relative volumes of the constituents, and the binding of the matrix and assumes that the composite is homogeneous and orthotropic. The elastic moduli and strength properties of unidirectional composites are determined by performing laboratory tests. The unidirectional property data is then used to predict the strength and stiffness of multidirectional laminates subjected to external loads.

The macromechanical analysis of composites is basically the classical structural analysis, with the exception that composite properties are controlled in both magnitude and direction. The purpose in controlling the properties is to tailor the strength and stiffness to obtain the greatest structural efficiency possible. This analytical method determines the strength and stiffness of a multi-layered plate-form composite structure when the properties of the individual lamina are known. The mathematical model for a composite is homogeneous and anisotropic. By assuming a plate-form (plane stress) structure the mathematical model can be assumed to be homogeneous and orthotropic.

Because of the high stress levels and complex materials combinations in the lug area, the upper drag brace design procedure consisted of a finite element analysis in the lug area and a conventional buckling analysis of the brace as a whole.

1. FINITE ELEMENT ANALYSIS

The stress distribution for the lug area was developed by a matrix displacement method of analysis based upon finite element idealization consisting of an assembly of two-dimensional isoparametric elements defined by four nodal points having two degrees of freedom at each node, translations in the nodal X and Y directions. The computer program used in this analysis is ANSYS, a large-scale program offering the most complete library of elements, as well as higher order elements than other programs designed for this application. ANSYS also introduces the stiffness of the attaching pin and titanium bushing.

A detailed layout of elements in the lug area with individual element numerical identifications is shown in Figure B-1. In addition, a typical layout by material type is shown in Figure B-2. For each computer run, a figure showing the material types (as Figure B-2) and a print-out of stresses and margins of safety by element was provided.

Allowable stresses used in the composite design are as follows:

Hercules 3501/AS Composite, 63% Fiber Volume:

- Ultimate stress in tension, 0^{o} ($F_{tu}0^{o}$) = 195,000 psi
- Ultimate stress in compression, 0^{o} ($F_{cu}0^{o}$) = 195,000 psi
- Ultimate stress in tension, 90^{o} ($F_{tu}90^{o}$) = 8,000 psi
- Ultimate stress in compression, 90^{o} ($F_{cu}90^{o}$) = 35,000 psi
- Allowable shear stress (F_s) = 8,000 psi
- Modulus of elasticity in tension (E_T) at 0^{o} = 18.0×10^6 psi
- Modulus of elasticity in tension (E_C) at 0^{o} = 18.0×10^6 psi
- Modulus of elasticity in tension (E_T) at 90^{o} = 1.2×10^6 psi
- Modulus of elasticity in tension (E_C) at 90^{o} = 1.2×10^6 psi

Hysol EA 934 Adhesive (See Appendix A):

- Peak allowable shear stress (F_{su}) = 7,800 psi
- Modulus of elasticity (E) = 0.37×10^6 psi
- Modulus of rigidity (G) = 0.144×10^6 psi
- Poisson's ratio (σ) = 0.28

For the 3501/AS graphite epoxy composite material, the above stresses are the ideal values for unidirectional material developed under test conditions. The basic advantage of composite fabrication

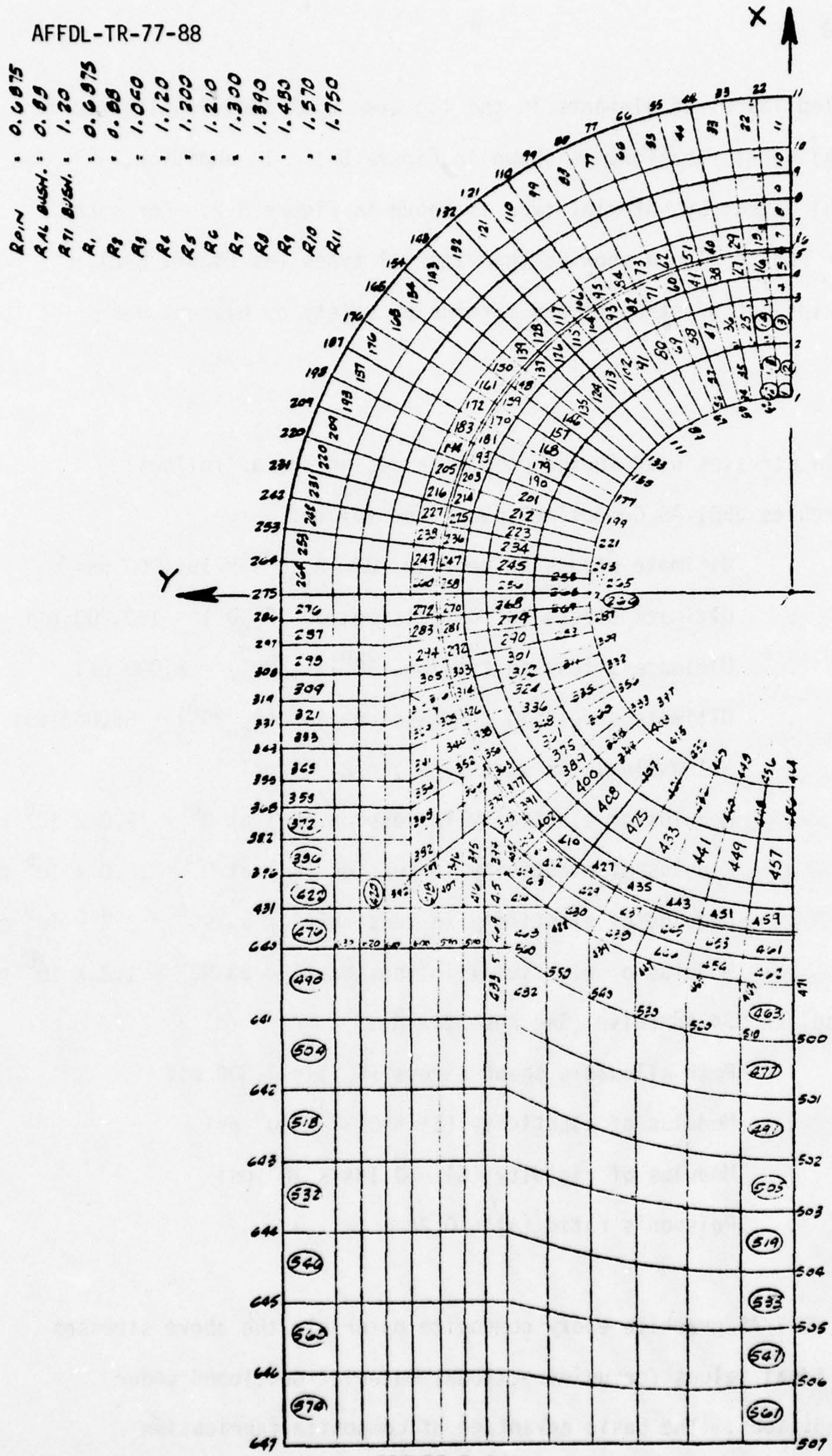
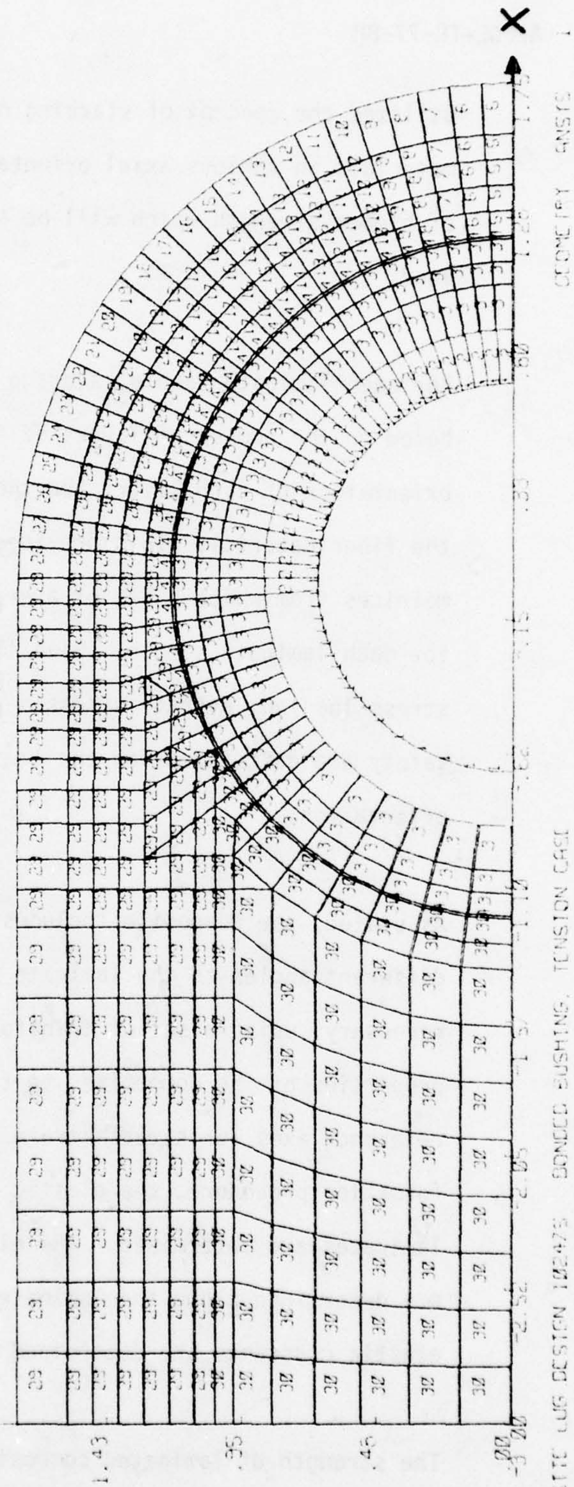


FIGURE B-1
Composite Lug Design Bonded Titanium Bushing



Material Code

Material Number	
1	Steel pin idealization
2	Aluminum-nickel-bronze bushing idealization
3	6-6-2 titanium bushing idealization
4	Hysol EA-934 adhesive for the bonded configurations, and replaced by titanium in the slip-fit bushing (no bond) configurations
5 - 28	Racetrack material properties rotated into the global X and Y axis of the model
29	Racetrack material properties, not rotated, since the global axis and the racetrack axis are the same
30	A fiber layup consisting of 46% of the fibers along the X axis, 19% at plus 45 degrees, 19% at -45 degrees to the X axis, and 16% along Y axis of model

FIGURE B-2
Composite Lug Design Material Layout

utilizes the concept of stacking of several layers of fiber materials in various axial orientations to develop a laminate material of higher strength which will be sufficient to carry an applied stress load.

For each laminate sample, average elastic constants must be determined based on the number of layers of fiber material, its thickness, the orientation of each layer, and the ideal mechanical properties of the fiber material. This provides composite stiffness and compliance matrices from which a set of average elastic constants is obtained for each laminate sample. With these elastic constants and the input stress loading, average stresses and strains and design margins of safety are calculated for the laminate as well as for each layer orientation.

As stated, the composite includes several laminae oriented at different angles to the laminate axis of symmetry. It is therefore necessary, using a set of transformation equations for the elastic properties of the composite, to transform lamina to the laminate reference axes for stress-strain determinations. Using this transformation procedure, the elastic constants for multidirectional laminates are determined. The elastic constants for each lamina are determined along the laminate reference axes and the laminate elastic constants are determined by a summation process.

The strength of laminated composites, like laminate stiffness, is determined on the macroscopic level. The orthotropic strength properties are determined by subjecting unidrectional laminates to

simple tension, compression, and shear loadings to determine allowable stresses. These properties are then used with an appropriate failure criterion for combined loadings to determine the strength of multidirectional laminated composites. The lamina margin of safety is given by the following equation which is obtained from Hill's anisotropic generalization of Van Mises' yield criterion for isotropic materials:

$$M.S. = \frac{1}{U} - 1$$

where U, the factor of utilization is given by:

$$U = \left(\frac{\sigma_L}{F_L}\right)^2 - \left(\frac{\sigma_L \sigma_T}{F_L^2}\right) + \left(\frac{\sigma_T}{F_T}\right)^2 + \left(\frac{\sigma_S}{F_S}\right)^2$$

σ_L = applied stress along fiber axis

σ_T = applied transverse stress

σ_S = applied shear stress

F_L = allowable stress along fiber axis

F_T = allowable transverse stress

F_S = allowable shear stress

The margin of safety in the adhesive bond line was calculated based on the maximum shear stress at an element using the allowable peak shear stress of 7,800 psi calculated in Appendix A.

A thorough derivation of this method of analysis of composite materials is presented in McDonnell Aircraft Report 338, 2 January 1969.

The finite element analysis in the lug area used the ANSYS computer program, which incorporates the above theoretical approach. The stress and margin of safety printouts for the final design, bonded titanium bushing, for both tension and compression loadings are presented in Tables B-1 (pages 81 through 88) and B-2 (pages 89 through 96), respectively.

These tables summarize the following stresses and margin of safety.

SX	- element stress in X direction
SY	- element stress in Y direction
SXY	- element shear stress
Smax	- maximum principal stress
Smin	- minimum principal stress
MS1	- margin of safety based on SX, SY, SXY
MS2	- margin of safety based on Smax and Smin

2. BUCKLING ANALYSIS

A conventional buckling analysis of the composite upper drag brace was performed for the brace and its components. Mechanical properties of the 3501/AS graphite epoxy composite and EA 934 adhesive are as used in the finite element analysis:

3501/AS Graphite Epoxy Components:

$F_{tu}0^{0}$ = 195,000 psi

$F_{cu}0^{0}$ = 195,000 psi

$F_{tu}90^{0}$ = 8,000 psi

$F_{cu}90^{0}$ = 35,000 psi

F_{s} = 8,000 psi

$E_{T}0^{0}$ = 18.0×10^{6} psi

$E_{C}0^{0}$ = 18.0×10^{6} psi

$E_{T}90^{0}$ = 1.2×10^{6} psi

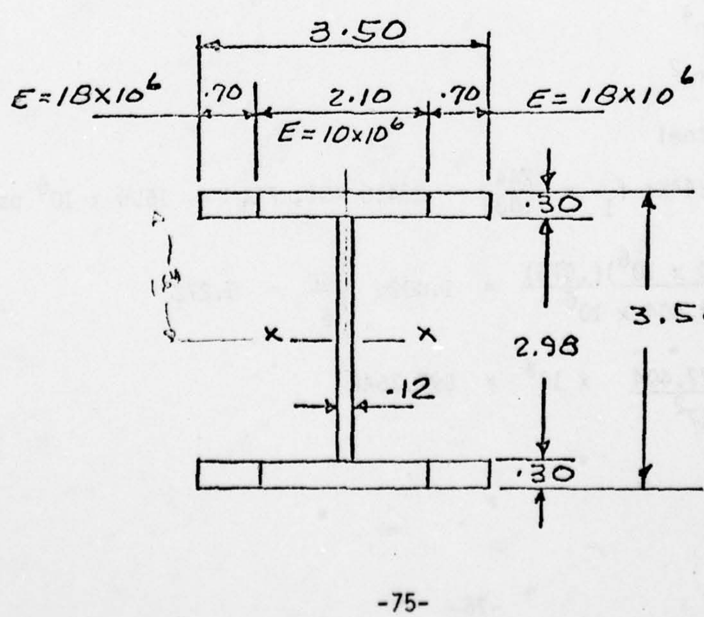
$E_{C}90^{0}$ = 1.2×10^{6} psi

EA 934 Adhesive:

F_{su} = 7,800 psi

The design compression load of 156,300 pounds occurs at reverse braking.

The buckling properties of the drag brace are:



$$EI_x = (10 \times 10^6)(2)\left[\frac{2.1 \times .3^3}{12} + 2.1 \times .3 \times 1.64^2 + \frac{.12 \times 2.98^3}{24}\right]$$

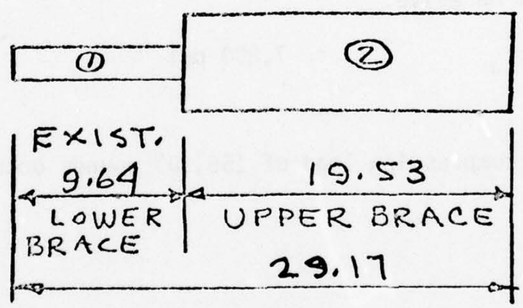
$$+ (18 \times 10^6)(4)\left[\frac{.7 \times .3^3}{12} + .7 \times .3 \times 1.64^2\right]$$

$$= (20 \times 10^6)\left[.0047 + 1.694 + 0.132\right] + (72 \times 10^6)\left[.00167 + .565\right]$$

$$= (36.624 \times 10^6) + (40.780 \times 10^6)$$

$$= 77.404 \times 10^6 \text{ lbs-in}^2$$

A basic column check was completed for the composite upper drag brace in assembly with the standard 300M steel lower brace, an asymmetrical stepped column assembly, by the method developed in McDonnell Aircraft Report 339, 2 January 1969, revised 1 December 1971, and using Figure B-3 contained therein.



$I_1 = .675 \text{ in}^4$

$A_1 = 1.039 \text{ in}^2$

$1 = \text{300M Steel}$

Assume P_{cr} - 244K; $f_1 = \frac{244}{1.039} = 234.0$ KSI; $Et_1 = 15.0 \times 10^6$ psi

$$\frac{E_1 I_1}{E_2 I_2} = \frac{(15.0 \times 10^6)(.576)}{77.404 \times 10^6} = 1.002 \qquad \frac{P_{cr}}{P_e} = 0.272$$

$$P_e = \frac{\pi^2 \times 77.404}{29.17^2} \times 10^6 = 897.764\text{K}$$

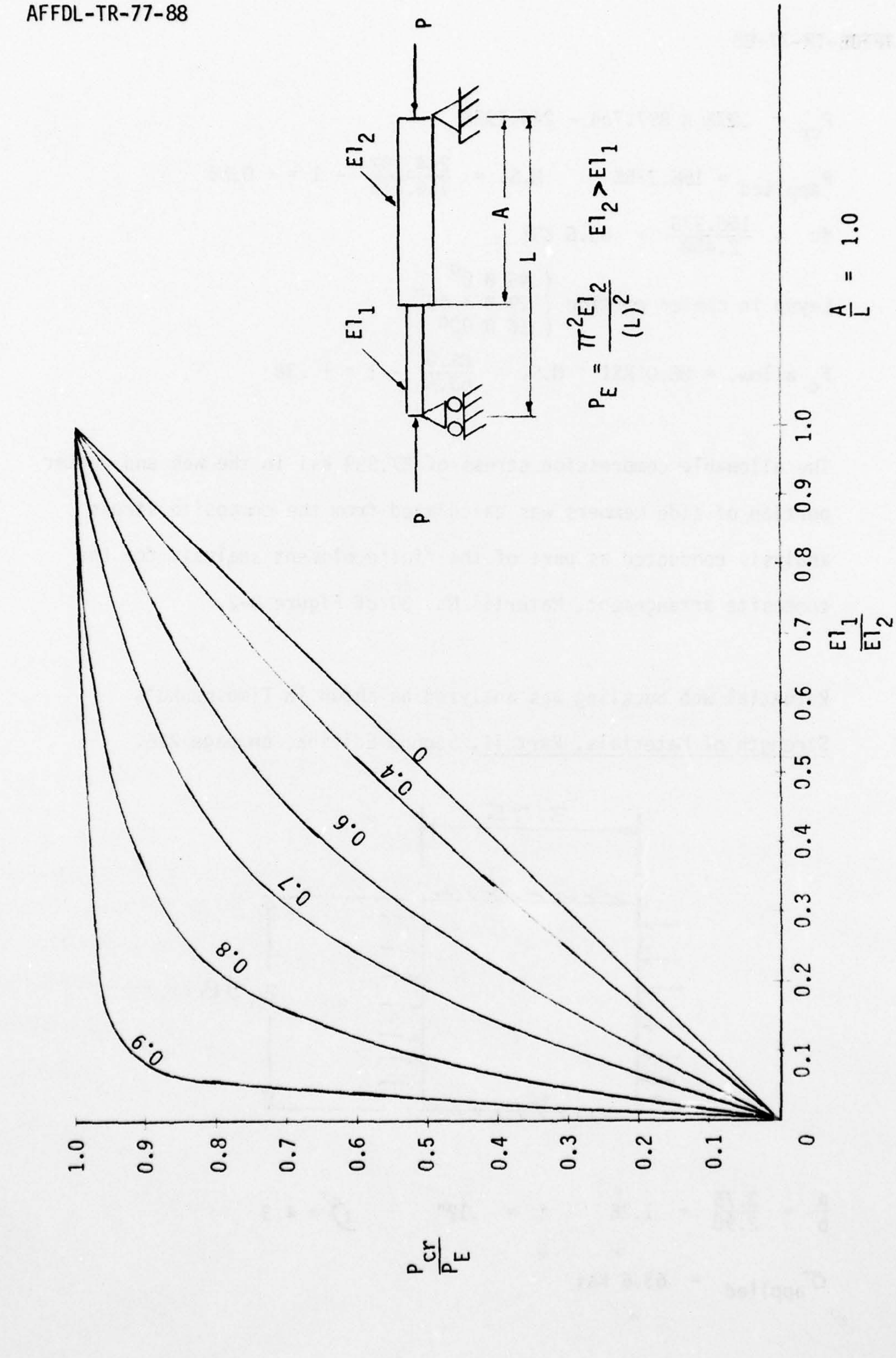


FIGURE B-3
Critical Loads for Unsymmetrical Stepped Columns

P_{cr} = .272 x 897.764 - 244.192K

$P_{applied}$ = 156.275K M.S. = $\frac{244.192}{156.275}$ - 1 = + 0.56

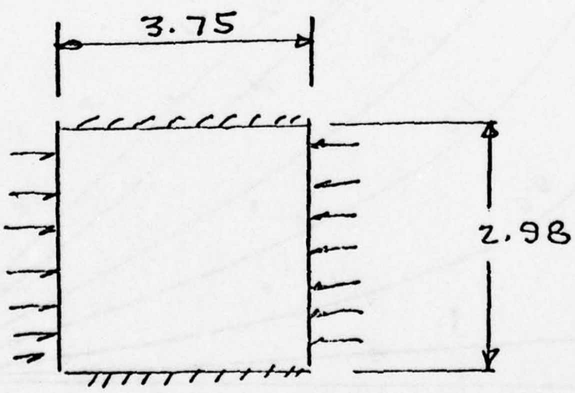
fc = $\frac{156.275}{2.458}$ = 63.6 KSI

Layup in center portion (46 @ 0^{o} (19 @ $\pm 45^{o}$ (16 @ 90^{o}

F_c allow. = 88.0 KSI M.S. = $\frac{88.0}{63.6}$ - 1 = + .38

The allowable compression stress of 87.999 ksi in the web and center portion of side members was calculated from the composite stress analysis conducted as part of the finite element analysis for the composite arrangement, Material No. 30 of Figure B-2.

Potential web buckling was analyzed as shown in Timoshenko's <u>Strength of Materials, Part II</u>, Second Edition, on page 225.



$\frac{a}{b}$ = $\frac{3.75}{2.98}$ = 1.26 t = .12" β = 4.3

$\sigma_{applied}$ = 63.6 ksi

$$\sigma_e = \frac{\pi^2 E t^2}{12 b^2 (1-\mu^2)} = \frac{\pi^2 \times 10.00 \times .12^2}{12 \times 2.98^2 (1-.34^2)} \times 10^6 = 15080 \text{ psi}$$

$$\sigma_{cr} = \beta\sigma_e = 4.3 \times 15.08 = 64.84 \text{ ksi} \qquad \text{M.S.} = \frac{64.84}{63.6} - 1 = +.02$$

The web shear strength at the side members was found to be satisfactory under this loading and the allowable bonding adhesive shear stress.

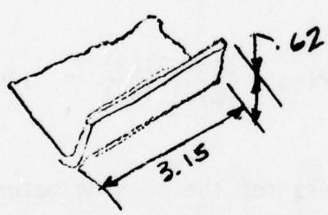
$$\text{Web load} = \frac{\text{web area}}{\text{total area}} \times 156.275 \text{ K}$$

$$\text{Web load} = \frac{.12 \times 2.98}{2.458} \times 156.275 = 22.74 \text{ K}$$

$$\text{Per side} = \frac{22.74}{2} = 11.37 \text{ K}$$

$$fs = \frac{11.37}{3.15 \times .62} = 5.82 \text{ KSI} \qquad F_s = 7.8 \text{ KSI adhesive}$$

$$\text{M.S.} = \frac{7.8}{5.82} - 1 = +\ 3.4$$



Under the design compression loading, the lower end gussets were in tension. Accordingly, the gusset and the gusset bond line were analyzed under the resulting tension load.

Assume tension load $= 0.05 \times P_{ult.}$

$= (0.05)(156{,}300)$

$= 7.81\text{K}$

$$\text{Tension in gusset} = \frac{\text{Load}}{\text{Area}}$$

$$= \frac{7.81}{(.65)(.15)}$$

$$= 80.1 \text{ ksi}$$

$$\text{Margin of safety} = \frac{\text{Allowable Tension}}{\text{Tension Load}} - 1$$

$$= \frac{88.0}{80.1} - 1 = 0.10$$

$$\text{Tension in adhesive} = \frac{7.81}{(1.3)(1.0)}$$

$$= 6.01 \text{ ksi}$$

$$\text{Margin of safety} = \frac{7.8}{6.01} - 1 = 0.30$$

The final analysis considered the design compression load of the bearing on the bushing.

$$\text{Bearing area} = (1.375)(0.840) = 1.155 \text{ sq. in.}$$

$$\text{Bearing factor} = 2.0$$

$$\text{Stress in each bearing} = \frac{(156.3)(2)}{(2)(1.155)} = 135.0 \text{ ksi}$$

Since the allowable stress for the bushing material is 135.0 ksi,

$$\text{Margin of safety} = \frac{135}{135} - 1 = 0$$

which is just adequate for the applied load.

TABLE B-1: SUMMARY OF STRESSES AND MARGINS OF SAFETY 24.0

COMPOSITE LUG DESIGN; BONDED BUSHING, TENSION LOADING

COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S. BONDED BUSHING, TENSION

FIBER STRESSES
R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM		SX	SY	SXY	SMAX	SMIN	MS1	MS2
7	R	-4.91	30.29	-1.15	30.33	-4.85	3.60	3.60
8	R	-3.20	16.81	-.50	16.82	-3.22	6.53	6.60
9	R	-2.28	13.97	-.44	13.99	-2.29	8.80	8.86
10	R	-1.52	12.32	-.39	12.33	-1.53	11.44	11.50
11	R	-.54	10.96	-.36	10.97	-.55	15.72	15.73
18	R	-4.59	27.86	-3.42	28.22	-4.94	3.71	3.74
19	R	-3.06	17.10	-1.53	17.21	-3.18	5.93	6.57
20	R	-2.15	13.87	-1.29	13.97	-2.26	8.35	8.94
21	R	-1.40	12.32	-1.17	12.41	-1.50	10.98	11.52
22	R	-.44	10.91	-1.06	11.01	-.54	15.56	15.72
29	R	-4.21	23.68	-5.49	24.72	-5.25	3.48	3.88
30	R	-2.92	17.20	-2.67	17.55	-3.27	5.22	6.39
31	R	-1.98	13.76	-2.13	14.04	-2.26	7.37	8.90
32	R	-1.25	12.28	-1.93	12.55	-1.52	9.95	11.38
33	R	-.28	10.84	-1.76	11.11	-.55	15.06	15.54
40	R	-3.53	18.81	-7.09	20.87	-5.59	2.76	4.00
41	R	-2.65	16.48	-3.97	17.27	-3.45	5.21	6.23
42	R	-1.72	13.66	-2.98	14.21	-2.28	6.35	8.81
43	R	-.98	12.21	-2.68	12.73	-1.50	8.67	11.30
44	R	-.01	10.76	-2.45	11.29	-.54	14.27	15.33
51	R	-2.67	14.23	-8.06	17.46	-5.90	2.16	4.05
52	R	-2.24	14.78	-5.27	16.28	-3.74	5.77	6.07
53	R	-1.42	13.28	-3.92	14.26	-2.40	5.84	8.56
54	R	-.66	12.06	-3.43	12.92	-1.53	7.46	11.11
55	R	.33	10.68	-3.13	11.55	-.54	13.00	14.99
62	R	-1.80	10.46	-8.48	14.79	-6.13	1.88	4.07
63	R	-1.71	12.46	-6.37	14.90	-4.15	5.78	5.81
64	R	-1.08	12.37	-4.94	13.98	-2.70	6.06	8.10
65	R	-.34	11.71	-4.25	13.06	-1.69	6.76	10.64
66	R	.73	10.58	-3.84	11.90	-.59	11.66	14.44
73	R	-.92	7.63	-8.42	12.80	-6.08	1.90	4.23
74	R	-.99	10.05	-7.06	13.49	-4.44	5.17	5.68
75	R	-.56	10.95	-5.86	13.41	-3.02	6.78	7.70
76	R	.11	11.00	-5.10	13.02	-1.90	6.84	10.14
77	R	1.24	10.37	-4.60	12.28	-.67	10.90	13.82
84	R	-.09	5.59	-8.10	11.33	-5.83	2.14	4.51
85	R	-.15	7.95	-7.36	12.31	-4.50	4.79	5.74
86	R	.18	9.33	-6.52	12.72	-3.21	7.38	7.53
87	R	.77	9.96	-5.85	12.80	-2.07	7.62	9.84
88	R	1.93	9.99	-5.34	12.65	-.73	10.84	13.30
95	R	.61	4.14	-7.70	10.27	-5.53	2.56	4.85
96	R	.69	6.25	-7.42	11.39	-4.45	4.75	5.92
97	R	1.03	7.75	-6.91	12.07	-3.30	7.52	7.53
98	R	1.59	8.71	-6.42	12.50	-2.19	8.68	9.69
99	R	2.77	9.37	-6.02	12.94	-.80	11.32	12.88
106	R	1.23	3.12	-7.33	9.56	-5.22	3.16	5.21
107	R	1.51	4.90	-7.33	10.73	-4.32	4.97	6.17
108	R	1.95	6.33	-7.09	11.56	-3.28	7.46	7.67

25.0

(cont'd)

COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S. BONDED BUSHING, TENSION

FIBER STRESSES
R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM		SX	SY	SXY	SMAX	SMIN	MS1	MS2
109	R	2.54	7.42	-6.78	12.19	-2.23	9.58	9.74
110	R	3.74	8.57	-6.53	13.12	-.81	12.04	12.69
117	R	1.74	2.35	-7.08	9.13	-5.05	3.90	5.43
118	R	2.26	3.79	-7.25	10.32	-4.26	5.27	6.30
119	R	2.85	5.05	-7.17	11.21	-3.30	7.24	7.71
120	R	3.52	6.15	-6.99	11.94	-2.28	9.66	9.71
121	R	4.74	7.58	-6.87	13.18	-.86	12.48	12.53
128	R	2.25	1.75	-6.91	8.92	-4.92	4.74	5.60
129	R	3.05	2.89	-7.16	10.13	-4.19	5.63	6.42
130	R	3.83	3.94	-7.15	11.03	-3.27	7.05	7.82
131	R	4.58	4.95	-7.02	11.79	-2.26	9.17	9.83
132	R	5.79	6.51	-6.97	13.13	-.84	12.44	12.62
139	R	2.78	1.22	-6.90	8.94	-4.94	5.35	5.57
140	R	3.87	2.06	-7.14	10.16	-4.23	5.85	6.36
141	R	4.84	2.90	-7.11	11.04	-3.31	6.68	7.74
142	R	5.67	3.78	-6.95	11.74	-2.29	8.03	9.77
143	R	6.75	5.36	-6.87	12.96	-.85	11.66	12.75
150	R	3.38	.72	-7.02	9.19	-5.09	5.36	5.37
151	R	4.80	1.27	-7.18	10.42	-4.36	5.87	6.15
152	R	5.95	1.89	-7.04	11.25	-3.40	6.14	7.52
153	R	6.82	2.64	-6.77	11.81	-2.35	6.65	9.59
154	R	7.63	4.15	-6.53	12.65	-.87	10.22	12.98
161	R	4.17	.25	-7.23	9.69	-5.28	4.79	5.13
162	R	5.95	.53	-7.21	10.95	-4.46	5.80	5.95
163	R	7.27	.96	-6.87	11.67	-3.45	5.51	7.35
164	R	8.07	1.58	-6.40	12.00	-2.35	5.34	9.51
165	R	8.35	3.01	-5.94	12.20	-.84	8.66	13.50
172	R	5.22	-.27	-7.55	10.50	-5.56	3.93	4.81
173	R	7.40	-.22	-7.24	11.77	-4.60	5.59	5.70
174	R	8.79	.06	-6.59	12.33	-3.48	4.74	7.16
175	R	9.38	.59	-5.86	12.32	-2.34	4.20	9.42
176	R	8.82	1.93	-5.15	11.58	-.82	7.30	14.20
183	R	6.71	-.77	-7.89	11.70	-5.76	3.19	4.55
184	R	9.26	-.92	-7.14	12.04	-4.60	5.41	5.56
185	R	10.55	-.71	-6.08	13.21	-3.37	3.94	7.15
186	R	10.68	-.20	-5.09	12.69	-2.21	3.35	9.57
187	R	8.98	1.05	-4.18	10.78	-.75	6.37	15.38
194	R	8.77	-1.27	-8.20	13.37	-5.86	2.65	4.36
195	R	11.59	-1.53	-6.82	14.49	-4.44	5.19	5.55
196	R	12.42	-1.30	-5.31	14.24	-3.11	3.22	7.33
197	R	11.77	-.74	-4.14	13.02	-1.99	2.82	9.94
198	R	8.78	.39	-3.16	9.83	-.66	5.94	17.03
205	R	11.65	-1.59	-8.28	15.63	-5.58	2.40	4.42
206	R	14.34	-1.83	-6.13	16.40	-3.89	4.86	5.89
207	R	14.16	-1.48	-4.26	15.25	-2.57	2.75	7.93
208	R	12.49	-.91	-3.08	13.16	-1.59	2.65	10.81
209	R	8.26	.04	-2.18	8.80	-.50	6.07	19.59
216	R	15.46	-1.82	-8.12	18.67	-5.04	2.33	4.56

26.0

(cont'd)

COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S. BONDED BUSHING, TENSION

FIBER STRESSES
R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM	SX	SY	SXY	SMAX	SMIN	MS1	MS2
217 R	17.19	-1.91	-5.13	18.48	-3.20	4.31	6.28
218 R	15.44	-1.44	-3.17	16.02	-2.02	2.63	8.57
219 R	12.76	-.91	-2.15	13.09	-1.24	2.82	11.71
220 R	7.53	-.14	-1.40	7.77	-.39	6.82	22.61
227 R	20.25	-1.76	-7.56	22.60	-4.11	2.41	4.81
228 R	19.64	-1.63	-3.98	20.36	-2.35	4.23	6.75
229 R	16.15	-1.16	-2.23	16.43	-1.45	3.06	9.29
230 R	12.72	-.77	-1.43	12.87	-.92	3.47	12.67
231 R	6.77	-.19	-.79	6.86	-.28	8.14	26.19
238 R	25.65	-1.38	-6.71	27.23	-2.96	2.32	4.90
239 R	21.32	-1.10	-2.98	21.71	-1.48	5.39	7.15
240 R	16.48	-.78	-1.60	16.62	-.93	4.53	9.93
241 R	12.62	-.55	-.93	12.68	-.61	4.94	13.53
242 R	6.10	-.16	-.37	6.12	-.18	10.36	29.99
249 R	31.12	-.60	-5.72	32.12	-1.60	1.79	4.72
250 R	22.23	-.33	-2.37	22.47	-.58	7.41	7.48
251 R	16.80	-.27	-1.29	16.90	-.37	8.87	10.34
252 R	12.60	-.23	-.65	12.63	-.26	8.93	14.18
253 R	5.63	-.05	-.12	5.63	-.05	15.16	33.45
260 R	35.98	.31	-4.93	36.65	-.36	.98	4.29
261 R	22.91	.39	-2.24	23.14	.17	3.48	7.35
262 R	17.33	.23	-1.28	17.43	.13	6.84	10.08
263 R	12.85	.09	-.63	12.88	.06	12.99	14.10
264 R	5.45	.07	-.04	5.45	.07	28.63	33.71
272 R	39.59	1.33	-4.40	40.09	.83	.66	3.46
273 R	23.92	1.08	-2.49	24.19	.81	1.82	5.54
274 R	18.08	.73	-1.52	18.21	.60	3.42	7.76
275 R	13.43	.41	-.83	13.48	.36	6.58	11.60
276 R	5.65	.15	-.11	5.66	.15	26.61	28.92
283 R	42.12	2.09	-4.08	42.53	1.68	.67	2.49
284 R	25.14	1.61	-2.96	25.50	1.25	1.32	4.25
285 R	18.92	1.07	-1.97	19.13	.86	2.45	6.32
286 R	14.15	.65	-1.15	14.25	.55	4.65	9.49
287 R	5.98	.22	-.30	5.99	.21	17.37	25.13
294 R	43.83	2.64	-3.92	44.20	2.27	.63	1.95
295 R	26.23	1.71	-3.59	26.74	1.19	.97	4.24
296 R	19.96	1.29	-2.44	20.27	.97	1.84	5.66
297 R	14.91	.78	-1.62	15.09	.60	3.29	8.83
298 R	6.50	.27	-.56	6.55	.22	11.05	23.14
305 R	45.88	2.15	-3.89	46.23	1.80	.69	2.23
306 R	26.97	1.96	-3.96	27.58	1.35	.79	3.85
307 R	21.07	1.30	-3.05	21.53	.84	1.37	5.93
308 R	15.74	.79	-2.13	16.04	.49	2.43	9.17
309 R	7.28	.28	-.85	7.38	.17	7.57	22.65
316 R	49.34	2.06	-4.31	49.73	1.67	.57	2.18
317 R	36.83	1.23	-4.36	37.36	.71	.69	3.85
318 R	30.47	1.58	-4.93	31.28	.76	.52	4.54
319 R	21.74	1.06	-3.53	22.33	.48	1.13	6.97

(cont'd)

COMPOSITE LUG DESIGN 102475

SUMMARY OF STRESSES AND M.S. BONDED BUSHING, TENSION

FIBER STRESSES

R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM		SX	SY	SXY	SMAX	SMIN	MS1	MS2
320	R	16.82	.69	-2.60	17.23	.28	1.90	9.74
321	R	8.31	.24	-1.14	8.47	.09	5.64	21.56
328	R	52.22	2.81	-4.02	52.54	2.48	.54	1.59
329	R	35.88	.95	-4.65	36.49	.34	.62	4.26
330	R	31.59	.90	-4.60	32.27	.23	.65	4.99
331	R	22.65	.84	-3.83	23.30	.19	1.00	7.27
332	R	17.64	.54	-2.93	18.13	.05	1.62	9.75
333	R	9.36	.20	-1.34	9.56	.01	4.69	19.41
340	R	51.42	.56	-2.92	51.59	.40	1.20	2.74
341	R	35.70	1.15	-5.00	36.41	.44	.51	4.20
342	R	31.55	.51	-4.60	32.22	-.16	.67	5.04
343	R	23.49	.55	-4.07	24.19	-.15	.90	7.03
344	R	18.51	.37	-3.14	19.04	-.16	1.46	9.19
345	R	10.59	.14	-1.50	10.80	-.07	4.11	16.98
352	R	33.48	.02	-3.65	33.87	-.37	1.05	4.71
353	R	46.03	-.09	-3.17	46.25	-.31	1.17	3.20
354	R	38.55	.34	-5.57	39.35	-.46	.38	3.92
355	R	29.67	.11	-4.37	30.31	-.52	.76	5.35
356	R	24.82	.17	-4.12	25.49	-.49	.89	6.53
357	R	19.45	.16	-3.30	20.00	-.39	1.35	8.60
358	R	12.24	.06	-1.62	12.45	-.15	3.73	14.53
365	L	24.63	-.15	-6.35	26.16	-1.68	1.37	1.66
366	R	42.04	-1.12	-4.55	42.52	-1.59	.64	3.41
367	R	41.96	-.54	-3.23	42.20	-.78	1.18	3.55
368	R	38.01	-.53	-4.64	38.57	-1.09	.63	3.93
369	R	30.45	-.23	-4.39	31.07	-.85	.75	5.12
370	R	25.36	-.13	-3.97	25.96	-.73	.95	6.32
371	R	20.55	-.03	-3.32	21.07	-.56	1.33	8.04
372	R	14.07	-.01	-1.65	14.26	-.20	3.58	12.54
379	L	28.57	-1.81	-4.00	29.08	-2.32	1.28	1.37
380	R	45.01	-1.12	-3.43	45.26	-1.37	1.05	3.19
381	R	40.82	-.97	-3.16	41.06	-1.21	1.23	3.62
382	R	36.91	-.90	-4.00	37.33	-1.32	.86	4.04
383	R	30.87	-.61	-4.03	31.38	-1.12	.89	4.99
384	R	25.98	-.35	-3.76	26.51	-.88	1.05	6.12
385	R	21.57	-.19	-3.19	22.02	-.65	1.42	7.61
386	R	16.03	-.06	-1.60	16.19	-.22	3.62	10.93
393	L	27.52	-2.54	-2.67	27.76	-2.77	1.41	1.45
394	L	25.37	-2.62	-2.36	25.56	-2.82	1.60	1.64
395	R	44.34	-1.63	-2.78	44.51	-1.80	1.38	3.20
396	R	40.02	-1.34	-3.10	40.25	-1.57	1.27	3.65
397	R	37.76	-.95	-3.48	38.07	-1.26	1.09	3.96
404	L	26.67	-3.00	-1.32	26.73	-3.06	1.51	1.52
405	L	25.37	-3.15	-1.42	25.44	-3.22	1.61	1.63
412	L	24.10	-3.74	.91	24.13	-3.77	1.71	1.72
413	L	23.81	-3.19	.22	23.81	-3.19	1.79	1.79
414	L	23.60	-2.88	-.06	23.60	-2.88	1.84	1.84
415	L	24.00	-2.07	-1.02	24.04	-2.11	1.84	1.85

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COMPOSITE LUG DESIGN 102475

SUMMARY OF STRESSES AND M.S. BONDED BUSHING, TENSION

FIBER STRESSES

R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM	SX	SY	SXY	SMAX	SMIN	MS1	MS2
416 R	42.62	-1.86	-1.74	42.69	-1.93	2.17	3.34
417 R	39.57	-1.56	-2.62	39.74	-1.73	1.56	3.67
418 R	35.79	-1.13	-3.40	36.10	-1.44	1.15	4.18
419 R	30.94	-.79	-3.63	31.35	-1.20	1.08	4.98
420 R	26.49	-.51	-3.46	26.92	-.95	1.20	5.99
421 R	22.44	-.29	-2.98	22.82	-.68	1.56	7.31
422 R	17.81	-.10	-1.49	17.94	-.22	3.81	9.78
429 L	19.51	-3.74	3.11	19.92	-4.15	2.05	2.17
430 L	19.92	-3.28	2.62	20.22	-3.57	2.11	2.20
437 L	14.58	-3.03	4.20	15.53	-3.98	2.55	2.93
438 L	15.32	-2.56	3.78	16.09	-3.33	2.61	2.93
445 L	10.09	-1.99	4.10	11.34	-3.25	3.48	4.26
446 L	11.04	-1.59	3.80	12.09	-2.65	3.51	4.19
453 L	6.73	-1.03	2.93	7.71	-2.01	5.57	6.89
454 L	7.78	-.66	2.74	8.59	-1.47	5.46	6.55
461 L	4.94	-.46	1.06	5.14	-.66	11.05	11.99
462 L	6.04	-.12	.99	6.20	-.27	9.76	10.35
463 L	7.51	.24	.85	7.60	.14	8.27	8.55
464 L	8.95	-.23	2.34	9.51	-.79	5.46	6.22
465 L	11.63	-1.04	3.26	12.42	-1.83	3.74	4.31
466 L	15.09	-1.93	3.32	15.72	-2.55	2.85	3.15
467 L	18.93	-2.57	2.37	19.18	-2.83	2.34	2.44
468 L	21.49	-2.62	.89	21.53	-2.65	2.10	2.11
469 L	22.89	-2.14	-.41	22.89	-2.14	1.98	1.98
470 R	41.00	-1.85	-1.22	41.04	-1.89	2.72	3.51
471 R	38.33	-1.54	-2.13	38.45	-1.65	1.97	3.84
472 R	34.94	-1.24	-2.88	35.16	-1.47	1.47	4.30
473 R	30.90	-.88	-3.22	31.23	-1.20	1.30	5.00
474 R	26.87	-.59	-3.12	27.22	-.94	1.41	5.92
475 R	23.23	-.34	-2.71	23.54	-.65	1.79	7.08
476 R	19.46	-.12	-1.35	19.56	-.21	4.10	8.90
477 L	9.09	.54	.63	9.14	.49	6.95	7.05
478 L	10.13	.20	1.75	10.43	-.10	5.46	5.87
479 L	12.02	-.38	2.49	12.51	-.86	4.13	4.54
480 L	14.50	-1.06	2.67	14.94	-1.51	3.28	3.55
481 L	17.08	-1.65	2.22	17.34	-1.91	2.78	2.90
482 L	19.68	-2.11	1.24	19.75	-2.18	2.40	2.42
483 L	21.27	-1.87	.19	21.28	-1.88	2.22	2.22
484 R	38.40	-1.70	-.59	38.41	-1.71	3.55	3.83
485 R	36.48	-1.46	-1.51	36.54	-1.52	2.69	4.10
486 R	33.78	-1.18	-2.20	33.92	-1.31	2.04	4.52
487 R	30.58	-.89	-2.55	30.79	-1.09	1.80	5.11
488 R	27.31	-.60	-2.55	27.54	-.83	1.87	5.88
489 R	24.32	-.36	-2.22	24.52	-.55	2.28	6.80
490 R	21.71	-.12	-1.09	21.77	-.18	4.66	7.91
491 L	10.27	.68	.47	10.29	.66	6.13	6.17
492 L	11.03	.43	1.30	11.19	.28	5.30	5.51
493 L	12.41	-.00	1.87	12.69	-.28	4.35	4.61

(cont'd)

COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S. BONDED BUSHING, TENSION

FIBER STRESSES
R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM	SX	SY	SXY	SMAX	SMIN	MS1	MS2
494 L	14.18	-.52	2.07	14.46	-.80	3.63	3.83
495 L	16.09	-.99	1.86	16.29	-1.19	3.13	3.24
496 L	17.92	-1.31	1.29	18.00	-1.39	2.79	2.83
497 L	19.06	-1.48	.75	19.09	-1.51	2.60	2.61
498 R	35.15	-1.37	-.00	35.15	-1.37	4.32	4.32
499 R	34.18	-1.22	-.84	34.20	-1.24	3.76	4.49
500 R	32.37	-1.00	-1.47	32.44	-1.07	2.99	4.82
501 R	30.09	-.77	-1.80	30.19	-.87	2.64	5.29
502 R	27.68	-.53	-1.84	27.80	-.65	2.68	5.88
503 R	25.51	-.31	-1.61	25.61	-.41	3.16	6.52
504 R	24.06	-.10	-.77	24.09	-.13	5.38	7.07
505 L	11.14	.74	.34	11.15	.73	5.60	5.62
506 L	11.71	.55	.95	11.79	.47	5.11	5.21
507 L	12.74	.22	1.38	12.89	.06	4.45	4.60
508 L	14.04	-.18	1.56	14.21	-.35	3.87	4.00
509 L	15.44	-.56	1.46	15.57	-.69	3.43	3.52
510 L	16.78	-.87	1.10	16.85	-.94	3.11	3.15
511 L	17.59	-.98	.70	17.61	-1.00	2.95	2.96
512 R	32.43	-.98	.23	32.43	-.98	4.76	4.84
513 R	32.22	-.91	-.41	32.23	-.91	4.64	4.90
514 R	31.15	-.77	-.92	31.17	-.79	4.00	5.12
515 R	29.59	-.60	-1.21	29.64	-.64	3.64	5.46
516 R	27.90	-.41	-1.26	27.95	-.47	3.67	5.89
517 R	26.40	-.24	-1.10	26.44	-.29	4.17	6.32
518 R	25.71	-.08	-.51	25.72	-.09	5.83	6.57
519 L	11.77	.75	.24	11.77	.75	5.26	5.27
520 L	12.21	.60	.67	12.25	.56	4.95	4.99
521 L	13.00	.34	.98	13.07	.26	4.48	4.56
522 L	13.99	.02	1.12	14.08	-.07	4.03	4.10
523 L	15.03	-.28	1.07	15.11	-.36	3.66	3.71
524 L	15.99	-.53	.85	16.04	-.57	3.38	3.41
525 L	16.58	-.65	.60	16.61	-.67	3.23	3.24
526 R	30.58	-.66	.27	30.59	-.67	5.12	5.26
527 R	30.71	-.63	-.17	30.71	-.63	5.19	5.24
528 R	30.17	-.55	-.55	30.18	-.56	4.83	5.37
529 R	29.17	-.43	-.77	29.19	-.45	4.58	5.61
530 R	28.02	-.30	-.82	28.05	-.32	4.64	5.90
531 R	27.04	-.17	-.71	27.05	-.19	5.06	6.18
532 R	26.79	-.06	-.32	26.80	-.06	5.99	6.27
533 L	12.20	.74	.16	12.20	.74	5.04	5.04
534 L	12.55	.62	.45	12.57	.60	4.82	4.84
535 L	13.19	.40	.65	13.22	.37	4.48	4.52
536 L	13.97	.14	.75	14.01	.10	4.12	4.16
537 L	14.78	-.10	.72	14.81	-.14	3.81	3.84
538 L	15.50	-.30	.59	15.52	-.33	3.57	3.59
539 L	15.94	-.41	.44	15.95	-.42	3.44	3.45
540 R	29.34	-.44	.24	29.34	-.44	5.45	5.57
541 R	29.67	-.43	-.06	29.67	-.43	5.50	5.50

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COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S. BONDED BUSHING, TENSION

FIBER STRESSES
R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM	SX	SY	SXY	SMAX	SMIN	MS1	MS2
542 R	29.46	-.39	-.31	29.46	-.39	5.36	5.56
543 R	28.85	-.30	-.46	28.86	-.31	5.26	5.71
544 R	28.10	-.21	-.50	28.10	-.22	5.35	5.91
545 R	27.46	-.12	-.43	27.47	-.13	5.62	6.08
546 R	27.47	-.04	-.18	27.47	-.04	6.00	6.09
547 L	12.47	.73	.09	12.47	.73	4.91	4.91
548 L	12.77	.63	.26	12.78	.62	4.74	4.75
549 L	13.31	.44	.37	13.32	.43	4.47	4.48
550 L	13.97	.21	.43	13.98	.20	4.17	4.18
551 L	14.63	.00	.42	14.64	-.01	3.91	3.91
552 L	15.21	-.17	.35	15.22	-.18	3.70	3.70
553 L	15.56	-.26	.27	15.57	-.27	3.58	3.58
554 R	28.59	-.30	.15	28.59	-.30	5.72	5.77
555 R	29.02	-.30	-.01	29.02	-.30	5.67	5.67
556 R	29.01	-.28	-.15	29.01	-.28	5.63	5.68
557 R	28.64	-.22	-.24	28.64	-.22	5.64	5.78
558 R	28.13	-.15	-.26	28.14	-.15	5.74	5.91
559 R	27.73	-.08	-.23	27.73	-.09	5.89	6.02
560 R	27.85	-.03	-.10	27.85	-.03	5.97	6.00
561 L	12.60	.73	.03	12.60	.73	4.84	4.84
562 L	12.88	.63	.08	12.88	.63	4.70	4.70
563 L	13.37	.45	.12	13.37	.45	4.46	4.46
564 L	13.97	.25	.14	13.97	.24	4.19	4.20
565 L	14.57	.05	.14	14.57	.05	3.95	3.95
566 L	15.08	-.11	.11	15.08	-.11	3.76	3.76
567 L	15.39	-.19	.09	15.39	-.19	3.65	3.65
568 R	28.24	-.23	.05	28.24	-.23	5.86	5.87
569 R	28.70	-.24	.00	28.70	-.24	5.76	5.76
570 R	28.79	-.22	-.05	28.79	-.22	5.74	5.74
571 R	28.53	-.18	-.07	28.53	-.18	5.79	5.81
572 R	28.15	-.12	-.08	28.15	-.12	5.89	5.91
573 R	27.85	-.07	-.07	27.85	-.07	5.98	5.99
574 R	28.02	-.02	-.03	28.02	-.02	5.95	5.96

THE MINIMUM MARGIN OF SAFETY IS .38 IN ELEMENT 354

THE MINIMUM MARGIN OF SAFETY IS 1.37 IN ELEMENT 379

AD-A052 764 CLEVELAND PNEUMATIC CO OH F/G 1/3
GRAPHITE COMPOSITE LANDING GEAR COMPONENT - UPPER DRAG BRACE HA--ETC(U)
SEP 77 M J BIEBER, W W FRICKER F33615-75-C-3152

UNCLASSIFIED AFFDL-TR-77-88 NL

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COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S.   BONDED BUSHING, TENSION

BOND LINE STRESSES

ELEM	SMAX	SMIN	MAXSHR	MS
6	-.36	-6.59	3.12	1.50
17	.50	-7.58	4.04	.93
28	1.30	-8.57	4.93	.58
39	1.82	-9.05	5.43	.44
50	1.96	-8.97	5.46	.43
61	1.88	-8.58	5.23	.49
72	1.76	-7.97	4.86	.60
83	1.55	-7.23	4.39	.78
94	1.31	-6.52	3.91	.99
105	1.08	-5.92	3.50	1.23
116	.88	-5.51	3.20	1.44
127	.73	-5.28	3.00	1.60
138	.62	-5.23	2.92	1.67
149	.57	-5.38	2.97	1.62
160	.62	-5.69	3.16	1.47
171	.75	-6.18	3.46	1.25
182	.98	-6.76	3.87	1.02
193	1.31	-7.30	4.31	.81
204	1.82	-7.74	4.78	.63
215	2.47	-8.05	5.26	.48
226	3.25	-8.07	5.66	.38
237	4.17	-7.71	5.94	.31
248	5.40	-7.13	6.27	.24
259	6.93	-6.61	6.77	.15
271	8.85	-6.46	7.65	.02
282	11.35	-6.84	9.10	-.14
293	14.00	-7.83	10.92	-.29
304	17.79	-8.37	13.08	-.40
315	19.98	-9.03	14.51	-.46
327	21.44	-10.73	16.08	-.52
339	25.83	-10.14	17.98	-.57
351	26.60	-9.02	17.81	-.56
364	24.80	-9.19	17.00	-.54
378	24.85	-8.65	16.75	-.53
392	24.47	-8.31	16.39	-.52
403	23.41	-8.27	15.84	-.51
424	21.50	-7.66	14.58	-.47
428	18.31	-6.63	12.47	-.37
436	14.68	-5.24	9.96	-.22
444	11.03	-3.51	7.27	.07
452	7.62	-1.44	4.53	.72
460	4.77	.72	2.03	2.84

THE MINIMUM MARGIN OF SAFETY IS   -.57 IN ELEMENT   339

TABLE B-2: SUMMARY OF STRESSES AND MARGINS OF SAFETY 33.0

COMPOSITE LUG DESIGN; BONDED BUSHING, COMPRESSION LOADING

COMPOSITE LUG DESIGN 102475

SUMMARY OF STRESSES AND M.S. BONDED BUSHING, COMPRESSION

FIBER STRESSES

R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM		SX	SY	SXY	SMAX	SMIN	MS1	MS2
7	R	-.18	-.79	-.04	-.17	-.79	97.44	43.24
8	R	-.10	-.66	-.03	-.09	-.67	130.98	51.69
9	R	-.05	-.58	-.02	-.05	-.58	178.65	58.92
10	R	-.02	-.44	-.01	-.02	-.44	267.13	78.17
11	R	-.01	-.15	-.00	-.01	-.15	730.73	229.52
18	R	-.14	-.81	-.12	-.12	-.83	40.27	41.15
19	R	-.07	-.70	-.09	-.06	-.72	50.76	47.97
20	R	-.03	-.62	-.05	-.03	-.62	69.87	55.46
21	R	-.01	-.47	-.03	-.01	-.48	106.85	72.62
22	R	-.01	-.17	-.01	-.00	-.17	287.11	201.38
29	R	-.07	-.84	-.19	-.03	-.89	25.25	38.52
30	R	-.02	-.77	-.14	-.00	-.80	30.88	42.93
31	R	-.00	-.68	-.08	.01	-.69	42.06	50.06
32	R	.01	-.53	-.04	.01	-.54	63.50	64.24
33	R	.00	-.22	-.01	.00	-.22	172.27	161.01
40	R	.02	-.89	-.22	.07	-.94	18.81	36.23
41	R	.04	-.86	-.16	.07	-.89	22.37	38.42
42	R	.04	-.76	-.09	.05	-.77	29.80	44.31
43	R	.04	-.62	-.04	.04	-.62	44.18	55.57
44	R	.01	-.28	-.00	.01	-.28	119.64	122.81
51	R	.13	-.94	-.24	.18	-.99	15.24	34.31
52	R	.12	-.95	-.15	.14	-.97	17.80	35.00
53	R	.10	-.86	-.08	.11	-.87	23.04	39.19
54	R	.07	-.72	-.02	.07	-.72	33.42	47.77
55	R	.02	-.37	.02	.02	-.37	88.99	92.65
62	R	.25	-1.00	-.22	.28	-1.04	12.88	32.63
63	R	.21	-1.03	-.12	.22	-1.04	14.96	32.45
64	R	.16	-.97	-.04	.16	-.97	18.89	35.10
65	R	.10	-.83	.03	.11	-.83	26.64	41.13
66	R	.02	-.48	.07	.03	-.49	69.53	70.55
73	R	.37	-1.05	-.18	.39	-1.07	11.27	31.36
74	R	.30	-1.10	-.06	.31	-1.11	13.01	30.48
75	R	.22	-1.06	.02	.22	-1.06	16.12	31.92
76	R	.14	-.94	.09	.15	-.95	22.14	35.87
77	R	.01	-.60	.14	.04	-.63	56.19	54.46
84	R	.49	-1.10	-.12	.50	-1.11	10.02	30.19
85	R	.39	-1.16	.02	.39	-1.16	11.53	28.91
86	R	.28	-1.14	.11	.29	-1.15	14.10	29.39
87	R	.16	-1.04	.18	.19	-1.07	18.98	31.71
88	R	-.02	-.73	.24	.05	-.80	46.83	42.85
95	R	.60	-1.15	-.03	.60	-1.15	8.96	29.01
96	R	.46	-1.21	.11	.47	-1.22	10.32	27.55
97	R	.32	-1.20	.22	.35	-1.23	12.52	27.31
98	R	.17	-1.12	.30	.24	-1.19	16.62	28.35
99	R	-.07	-.85	.36	.07	-.99	40.11	34.39
106	R	.71	-1.20	.07	.71	-1.20	8.02	27.78
107	R	.53	-1.24	.23	.56	-1.27	9.26	26.27
108	R	.35	-1.24	.35	.42	-1.31	11.22	25.50

(cont'd)

COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S. BONDED BUSHING, COMPRESSION

FIBER STRESSES
R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM	SX	SY	SXY	SMAX	SMIN	MS1	MS2
109 R	.15	-1.18	.43	.28	-1.31	14.81	25.60
110 R	-.17	-.95	.51	.08	-1.20	35.26	28.11
117 R	.81	-1.23	.19	.82	-1.25	7.20	26.49
118 R	.58	-1.26	.36	.65	-1.33	8.35	24.98
119 R	.35	-1.26	.49	.49	-1.40	10.13	23.85
120 R	.11	-1.22	.58	.33	-1.44	13.34	23.20
121 R	-.30	-1.04	.67	.10	-1.43	31.59	23.38
128 R	.90	-1.24	.34	.95	-1.30	6.48	25.45
129 R	.63	-1.26	.51	.76	-1.39	7.51	23.79
130 R	.34	-1.26	.65	.57	-1.49	9.16	22.35
131 R	.04	-1.23	.75	.38	-1.57	12.13	21.14
132 R	-.48	-1.09	.85	.11	-1.69	28.77	19.72
139 R	.99	-1.23	.52	1.10	-1.35	5.78	24.33
140 R	.65	-1.23	.69	.88	-1.46	6.74	22.64
141 R	.30	-1.22	.83	.66	-1.58	8.31	20.95
142 R	-.08	-1.19	.92	.44	-1.71	11.16	19.35
143 R	-.72	-1.10	1.03	.14	-1.95	26.72	16.88
150 R	1.07	-1.20	.73	1.28	-1.41	5.09	23.12
151 R	.65	-1.16	.90	1.02	-1.53	6.01	21.41
152 R	.21	-1.13	1.02	.76	-1.68	7.55	19.57
153 R	-.25	-1.10	1.10	.51	-1.86	10.39	17.72
154 R	-1.01	-1.06	1.19	.16	-2.23	25.61	14.68
161 R	1.11	-1.13	.96	1.47	-1.49	4.49	21.75
162 R	.59	-1.07	1.12	1.16	-1.63	5.38	20.01
163 R	.05	-1.01	1.22	.85	-1.81	6.95	18.11
164 R	-.50	-.98	1.27	.55	-2.03	9.94	16.15
165 R	-1.35	-.97	1.33	.18	-2.50	25.51	12.97
172 R	1.13	-1.02	1.25	1.70	-1.59	3.88	20.27
173 R	.48	-.91	1.38	1.33	-1.76	4.74	18.49
174 R	-.18	-.83	1.43	.96	-1.97	6.35	16.56
175 R	-.82	-.79	1.42	.62	-2.22	9.55	14.65
176 R	-1.73	-.83	1.41	.20	-2.76	25.71	11.65
183 R	1.09	-.86	1.56	1.96	-1.72	3.31	18.56
184 R	.27	-.70	1.65	1.50	-1.93	4.18	16.72
185 R	-.53	-.60	1.61	1.05	-2.18	5.92	14.87
186 R	-1.24	-.56	1.52	.66	-2.46	9.51	13.17
187 R	-2.13	-.64	1.42	.22	-2.99	27.16	10.67
194 R	.97	-.64	1.91	2.24	-1.90	2.91	16.69
195 R	-.09	-.45	1.90	1.63	-2.17	3.77	14.77
196 R	-1.02	-.34	1.74	1.09	-2.46	5.73	13.10
197 R	-1.74	-.32	1.55	.67	-2.74	9.84	11.73
198 R	-2.52	-.44	1.36	.23	-3.19	28.72	9.97
205 R	.68	-.38	2.23	2.45	-2.14	2.46	14.73
206 R	-.64	-.18	2.08	1.68	-2.50	3.57	12.75
207 R	-1.63	-.11	1.78	1.06	-2.80	5.91	11.39
208 R	-2.30	-.12	1.48	.63	-3.05	10.83	10.44
209 R	-2.85	-.28	1.22	.21	-3.33	31.75	9.49
216 R	.19	-.06	2.53	2.60	-2.47	2.19	12.70

35.0

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COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S. BONDED BUSHING, COMPRESSION

FIBER STRESSES
R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM		SX	SY	SXY	SMAX	SMIN	MS1	MS2
217	R	-1.37	.10	2.17	1.66	-2.92	3.53	10.81
218	R	-2.31	.13	1.72	1.01	-3.20	6.26	9.86
219	R	-2.83	.06	1.35	.60	-3.36	11.74	9.37
220	R	-3.11	-.13	1.05	.20	-3.44	32.58	9.16
227	R	-.56	.26	2.73	2.61	-2.91	2.06	10.70
228	R	-2.24	.35	2.13	1.55	-3.44	3.68	9.06
229	R	-2.99	.30	1.57	.93	-3.62	6.79	8.62
230	R	-3.31	.19	1.18	.55	-3.67	12.65	8.52
231	R	-3.32	-.02	.85	.19	-3.53	33.98	8.91
238	R	-1.58	.57	2.78	2.48	-3.49	2.05	8.84
239	R	-3.15	.53	1.98	1.39	-4.01	3.95	7.66
240	R	-3.60	.41	1.38	.85	-4.03	7.24	7.66
241	R	-3.73	.28	.98	.51	-3.96	13.31	7.82
242	R	-3.50	.06	.64	.17	-3.61	35.04	8.68
249	R	-2.82	.78	2.65	2.18	-4.22	2.17	7.18
250	R	-3.95	.61	1.75	1.21	-4.55	4.23	6.65
251	R	-4.13	.45	1.18	.74	-4.42	7.55	6.89
252	R	-4.11	.31	.79	.44	-4.24	13.76	7.24
253	R	-3.66	.09	.45	.15	-3.71	35.90	8.43
260	R	-4.11	.84	2.41	1.82	-5.09	2.30	5.83
261	R	-4.60	.61	1.52	1.02	-5.02	4.30	5.95
262	R	-4.62	.44	.99	.62	-4.81	7.33	6.26
263	R	-4.45	.30	.61	.38	-4.52	12.78	6.72
264	R	-3.83	.10	.28	.12	-3.85	31.34	8.08
272	R	-5.23	.73	2.11	1.40	-5.90	2.59	4.90
273	R	-5.18	.51	1.33	.80	-5.48	4.63	5.37
274	R	-5.07	.35	.84	.47	-5.19	7.70	5.73
275	R	-4.76	.23	.48	.28	-4.81	13.20	6.28
276	R	-4.03	.09	.16	.09	-4.03	31.69	7.68
283	R	-6.11	.47	1.86	.96	-6.60	3.16	4.29
284	R	-5.72	.31	1.18	.53	-5.95	5.48	4.88
285	R	-5.47	.21	.74	.31	-5.57	9.05	5.28
286	R	-5.06	.15	.39	.18	-5.09	16.20	5.87
287	R	-4.18	.06	.09	.06	-4.18	38.98	7.37
294	R	-6.83	.09	1.70	.49	-7.22	3.64	3.84
295	R	-6.21	.07	1.13	.27	-6.40	5.87	4.46
296	R	-5.87	.05	.70	.13	-5.95	9.83	4.88
297	R	-5.37	.05	.36	.07	-5.39	17.90	5.49
298	R	-4.30	.02	.05	.02	-4.30	42.59	7.15
305	R	-7.60	-.22	1.70	.15	-7.97	3.63	3.39
306	R	-6.63	-.21	1.16	-.00	-6.83	5.71	4.12
307	R	-6.29	-.13	.75	-.04	-6.38	9.04	4.49
308	R	-5.71	-.05	.38	-.02	-5.74	16.82	5.10
309	R	-4.41	-.01	.04	-.01	-4.41	42.18	6.94
316	R	-9.62	-.59	1.99	-.17	-10.04	2.93	2.49
317	R	-7.60	-.46	1.89	.01	-8.07	3.17	3.34
318	R	-7.30	-.43	1.39	-.16	-7.57	4.61	3.62
319	R	-6.73	-.24	.89	-.12	-6.85	7.61	4.11

36.0

(cont'd)

COMPOSITE LUG DESIGN 102475

SUMMARY OF STRESSES AND M.S. BONDED BUSHING, COMPRESSION

FIBER STRESSES

R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM		SX	SY	SXY	SMAX	SMIN	MS1	MS2
320	R	-6.11	-.13	.46	-.10	-6.15	14.29	4.70
321	R	-4.54	-.04	.07	-.04	-4.54	39.09	6.71
328	R	-9.13	-1.16	2.69	-.34	-9.95	1.93	2.52
329	R	-8.10	-.60	2.03	-.09	-8.61	2.89	3.07
330	R	-7.89	-.47	1.55	-.16	-8.20	4.06	3.27
331	R	-7.20	-.32	.99	-.18	-7.33	6.76	3.77
332	R	-6.46	-.18	.56	-.13	-6.51	11.88	4.38
333	R	-4.68	-.06	.12	-.06	-4.69	34.30	6.47
340	R	-9.56	-.98	3.15	.05	-10.59	1.52	2.31
341	R	-8.96	-.75	2.27	-.16	-9.54	2.48	2.67
342	R	-8.38	-.54	1.73	-.17	-8.75	3.53	3.00
343	R	-7.68	-.37	1.16	-.19	-7.86	5.65	3.46
344	R	-6.85	-.21	.68	-.14	-6.92	9.90	4.06
345	R	-4.89	-.07	.19	-.06	-4.89	28.35	6.15
352	R	-8.34	-.93	3.18	.25	-9.51	1.50	2.68
353	R	-9.86	-1.03	3.57	.23	-11.12	1.23	2.15
354	R	-9.85	-.72	2.62	-.02	-10.55	2.01	2.32
355	R	-9.31	-.56	2.01	-.12	-9.75	2.92	2.59
356	R	-8.29	-.37	1.35	-.14	-8.51	4.74	3.11
357	R	-7.39	-.22	.84	-.12	-7.49	7.95	3.68
358	R	-5.21	-.08	.27	-.06	-5.22	22.07	5.70
365	L	-4.28	-1.57	6.01	3.24	-9.09	3.23	3.95
366	R	-9.46	-1.13	4.65	.95	-11.53	.71	2.03
367	R	-11.31	-.91	3.82	.34	-12.56	1.08	1.78
368	R	-10.89	-.69	2.91	.08	-11.66	1.71	2.00
369	R	-10.17	-.47	2.20	.01	-10.65	2.57	2.29
370	R	-9.05	-.34	1.55	-.07	-9.32	4.03	2.76
371	R	-7.98	-.21	1.01	-.08	-8.11	6.56	3.32
372	R	-5.65	-.07	.37	-.05	-5.67	17.40	5.17
379	L	-6.51	-1.24	6.58	3.22	-10.96	2.80	3.19
380	R	-12.04	-1.17	5.13	.87	-14.08	.55	1.48
381	R	-12.51	-.85	4.11	.46	-13.82	.93	1.53
382	R	-12.18	-.50	3.14	.29	-12.97	1.52	1.70
383	R	-11.15	-.37	2.35	.12	-11.64	2.34	2.01
384	R	-9.86	-.27	1.71	.02	-10.16	3.56	2.45
385	R	-8.66	-.17	1.16	-.02	-8.82	5.58	2.97
386	R	-6.23	-.06	.46	-.03	-6.27	14.22	4.59
393	L	-9.10	-1.26	[illegible].13	2.96	-13.31	2.43	2.53
394	L	-9.45	-1.19	7.18	2.96	-13.61	2.39	2.46
395	R	-14.57	-.80	5.56	1.16	-16.53	.43	1.11
396	R	-14.05	-.62	4.23	.60	-15.27	.87	1.29
397	R	-13.18	-.57	2.95	.09	-13.83	1.67	1.53
404	L	-11.51	-1.24	8.14	3.25	-16.00	1.96	1.96
405	L	-10.88	-1.09	7.74	3.18	-15.14	2.12	2.12
412	L	-14.98	-.64	9.13	3.80	-19.42	1.57	1.44
413	L	-13.97	-.29	8.28	3.61	-17.87	1.81	1.65
414	L	-12.84	-.08	7.76	3.59	-16.50	2.01	1.85
415	L	-11.79	-.39	6.72	2.72	-14.91	2.44	2.19

37.0

(cont'd)

COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S. BONDED BUSHING, COMPRESSION

FIBER STRESSES
R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM		SX	SY	SXY	SMAX	SMIN	MS1	MS2
416	R	-17.73	-.50	5.67	1.20	-19.43	.40	.80
417	R	-15.27	-.40	4.34	.77	-16.45	.82	1.13
418	R	-13.50	-.38	3.28	.39	-14.28	1.40	1.45
419	R	-12.01	-.29	2.45	.20	-12.50	2.20	1.80
420	R	-10.63	-.21	1.83	.10	-10.95	3.26	2.20
421	R	-9.31	-.13	1.28	.04	-9.49	4.98	2.69
422	R	-6.86	-.05	.53	-.01	-6.90	12.35	4.07
429	L	-19.93	.99	9.68	4.78	-23.72	1.28	.99
430	L	-18.84	1.19	8.84	4.53	-22.18	1.46	1.13
437	L	-24.66	3.00	9.22	5.79	-27.45	1.13	.72
438	L	-23.37	2.88	8.39	5.33	-25.82	1.30	.83
445	L	-28.76	5.04	7.57	6.66	-30.38	1.09	.55
446	L	-27.26	4.71	6.86	6.12	-28.67	1.24	.64
453	L	-31.76	6.70	4.95	7.33	-32.38	1.09	.45
454	L	-30.10	6.16	4.48	6.71	-30.64	1.24	.54
461	L	-33.32	7.61	1.72	7.69	-33.39	1.11	.40
462	L	-31.57	6.96	1.56	7.02	-31.64	1.25	.49
463	L	-29.22	6.21	1.28	6.25	-29.26	1.46	.61
464	L	-27.99	5.59	3.71	5.99	-28.40	1.46	.66
465	L	-25.66	4.45	5.72	5.50	-26.71	1.47	.77
466	L	-22.44	2.99	7.08	4.83	-24.27	1.54	.95
467	L	-18.70	1.48	7.68	4.07	-21.29	1.69	1.23
468	L	-15.13	.53	7.45	3.51	-18.12	1.97	1.62
469	L	-12.08	.07	6.21	2.68	-14.69	2.63	2.24
470	R	-20.01	-.13	5.51	1.30	-21.44	.44	.63
471	R	-16.98	-.22	4.34	.84	-18.04	.82	.94
472	R	-14.70	-.20	3.33	.53	-15.43	1.37	1.27
473	R	-12.93	-.19	2.55	.30	-13.42	2.07	1.61
474	R	-11.40	-.14	1.91	.17	-11.72	3.06	1.99
475	R	-9.99	-.09	1.37	.09	-10.17	4.60	2.44
476	R	-7.58	-.03	.58	.01	-7.62	11.14	3.59
477	L	-26.81	5.34	.94	5.37	-26.84	1.73	.76
478	L	-25.92	4.93	2.73	5.17	-26.16	1.74	.81
479	L	-24.21	4.16	4.27	4.79	-24.84	1.78	.91
480	L	-21.89	3.16	5.40	4.28	-23.00	1.87	1.07
481	L	-19.18	2.07	6.04	3.67	-20.78	2.02	1.29
482	L	-16.25	1.20	6.28	3.23	-18.27	2.23	1.61
483	L	-14.21	.40	6.04	2.57	-16.38	2.52	1.93
484	R	-22.63	.25	5.16	1.36	-23.74	.52	.47
485	R	-19.26	.11	4.17	.97	-20.12	.88	.74
486	R	-16.46	.02	3.28	.65	-17.09	1.39	1.05
487	R	-14.35	-.02	2.56	.42	-14.79	2.05	1.37
488	R	-12.61	-.03	1.96	.27	-12.91	2.95	1.71
489	R	-11.07	-.03	1.43	.16	-11.25	4.32	2.11
490	R	-8.82	-.01	.63	.04	-8.86	10.05	2.95
491	L	-25.03	4.70	.70	4.72	-25.05	1.96	.90
492	L	-24.33	4.39	2.05	4.54	-24.48	2.00	.94
493	L	-23.02	3.82	3.21	4.20	-23.40	2.07	1.04

(cont'd)

COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S. BONDED BUSHING, COMPRESSION

FIBER STRESSES
R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM		SX	SY	SXY	SMAX	SMIN	MS1	MS2
494	L	-21.25	3.07	4.11	3.75	-21.93	2.18	1.18
495	L	-19.21	2.25	4.71	3.24	-20.20	2.33	1.37
496	L	-17.05	1.42	4.96	2.67	-18.30	2.57	1.63
497	L	-15.60	.95	4.80	2.24	-16.89	2.83	1.86
498	R	-25.58	.66	4.40	1.38	-26.30	.75	.33
499	R	-21.67	.44	3.70	1.04	-22.28	1.09	.57
500	R	-18.49	.27	3.00	.74	-18.96	1.57	.84
501	R	-16.04	.16	2.40	.51	-16.39	2.21	1.13
502	R	-14.08	.09	1.88	.34	-14.32	3.07	1.44
503	R	-12.43	.05	1.40	.20	-12.59	4.38	1.78
504	R	-10.46	.01	.62	.05	-10.50	9.63	2.33
505	L	-23.70	4.22	.52	4.23	-23.70	2.17	1.01
506	L	-23.13	3.97	1.52	4.05	-23.22	2.22	1.05
507	L	-22.08	3.51	2.39	3.73	-22.30	2.32	1.14
508	L	-20.68	2.90	3.08	3.30	-21.08	2.46	1.27
509	L	-19.09	2.23	3.55	2.81	-19.67	2.65	1.45
510	L	-17.49	1.59	3.80	2.32	-18.22	2.88	1.65
511	L	-16.38	1.13	3.79	1.92	-17.16	3.11	1.83
512	R	-27.25	.89	3.53	1.33	-27.68	1.11	.26
513	R	-23.46	.65	3.08	1.04	-23.85	1.43	.47
514	R	-20.09	.44	2.57	.76	-20.41	1.93	.71
515	R	-17.46	.29	2.10	.54	-17.71	2.58	.98
516	R	-15.36	.18	1.66	.36	-15.54	3.48	1.25
517	R	-13.68	.10	1.25	.21	-13.79	4.84	1.54
518	R	-12.00	.03	.55	.06	-12.03	9.82	1.91
519	L	-22.71	3.85	.38	3.85	-22.72	2.34	1.10
520	L	-22.24	3.63	1.10	3.68	-22.29	2.40	1.15
521	L	-21.37	3.24	1.73	3.36	-21.49	2.53	1.23
522	L	-20.22	2.73	2.23	2.95	-20.43	2.70	1.36
523	L	-18.93	2.17	2.59	2.49	-19.25	2.92	1.51
524	L	-17.65	1.62	2.80	2.02	-18.05	3.17	1.69
525	L	-16.78	1.25	2.81	1.68	-17.20	3.39	1.83
526	R	-28.28	1.01	2.68	1.25	-28.52	1.61	.23
527	R	-24.66	.77	2.40	.99	-24.88	1.96	.41
528	R	-21.30	.54	2.05	.73	-21.49	2.50	.63
529	R	-18.58	.37	1.69	.52	-18.73	3.23	.87
530	R	-16.42	.23	1.35	.34	-16.53	4.23	1.12
531	R	-14.73	.13	1.02	.20	-14.80	5.71	1.36
532	R	-13.32	.04	.45	.06	-13.34	10.30	1.62
533	L	-22.02	3.58	.25	3.58	-22.03	2.48	1.17
534	L	-21.61	3.39	.74	3.41	-21.64	2.55	1.22
535	L	-20.86	3.04	1.17	3.10	-20.91	2.69	1.30
536	L	-19.87	2.59	1.51	2.70	-19.97	2.89	1.42
537	L	-18.78	2.10	1.76	2.25	-18.93	3.13	1.56
538	L	-17.71	1.62	1.91	1.81	-17.90	3.40	1.72
539	L	-16.97	1.28	1.94	1.48	-17.18	3.62	1.85
540	R	-28.85	1.06	1.87	1.18	-28.96	2.30	.21
541	R	-25.43	.83	1.71	.94	-25.54	2.73	.37

39.0

(cont'd)

COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S. BONDED BUSHING, COMPRESSION

FIBER STRESSES
R = RACE TRACK ELEM, L = 46,19,19,16 LAYUP ELEM

ELEM	SX	SY	SXY	SMAX	SMIN	MS1	MS2
542 R	-22.13	.60	1.48	.69	-22.23	3.38	.57
543 R	-19.41	.41	1.24	.49	-19.49	4.26	.80
544 R	-17.23	.26	.99	.31	-17.28	5.42	1.02
545 R	-15.56	.14	.75	.18	-15.60	7.04	1.24
546 R	-14.35	.04	.33	.05	-14.36	10.84	1.44
547 L	-21.58	3.40	.15	3.40	-21.59	2.57	1.22
548 L	-21.21	3.23	.43	3.24	-21.22	2.65	1.26
549 L	-20.53	2.91	.68	2.93	-20.55	2.80	1.34
550 L	-19.64	2.50	.88	2.53	-19.67	3.01	1.46
551 L	-18.67	2.04	1.02	2.09	-18.72	3.28	1.59
552 L	-17.71	1.60	1.12	1.67	-17.78	3.56	1.75
553 L	-17.06	1.29	1.14	1.36	-17.13	3.79	1.86
554 R	-29.15	1.08	1.10	1.12	-29.19	3.18	.20
555 R	-25.88	.85	1.02	.89	-25.92	3.78	.35
556 R	-22.66	.62	.89	.66	-22.70	4.65	.54
557 R	-19.95	.43	.75	.46	-19.98	5.76	.75
558 R	-17.77	.27	.61	.29	-17.79	7.13	.97
559 R	-16.13	.15	.46	.16	-16.15	8.79	1.17
560 R	-15.05	.05	.20	.05	-15.05	11.29	1.33
561 L	-21.37	3.31	.05	3.31	-21.37	2.61	1.24
562 L	-21.02	3.15	.14	3.15	-21.02	2.69	1.29
563 L	-20.37	2.84	.22	2.84	-20.37	2.85	1.37
564 L	-19.52	2.45	.29	2.45	-19.53	3.08	1.48
565 L	-18.60	2.01	.33	2.02	-18.61	3.35	1.61
566 L	-17.71	1.59	.37	1.60	-17.72	3.65	1.76
567 L	-17.09	1.29	.37	1.30	-17.10	3.88	1.87
568 R	-29.28	1.09	.37	1.09	-29.28	3.96	.19
569 R	-26.09	.86	.34	.87	-26.10	4.79	.34
570 R	-22.91	.63	.30	.64	-22.92	5.94	.53
571 R	-20.22	.44	.25	.44	-20.22	7.32	.73
572 R	-18.04	.28	.20	.28	-18.04	8.84	.94
573 R	-16.42	.15	.15	.15	-16.42	10.32	1.13
574 R	-15.40	.05	.07	.05	-15.40	11.54	1.27

THE MINIMUM MARGIN OF SAFETY IS .40 IN ELEMENT 416

THE MINIMUM MARGIN OF SAFETY IS .19 IN ELEMENT 568

40.0

(cont'd)

COMPOSITE LUG DESIGN 102475
SUMMARY OF STRESSES AND M.S.   BONDED BUSHING, COMPRESSION

BOND LINE STRESSES

ELEM	SMAX	SMIN	MAXSHR	MS
6	-.04	-.26	.11	72.04
17	.06	-.35	.20	37.20
28	.19	-.44	.31	23.86
39	.31	-.52	.42	17.64
50	.44	-.60	.52	14.05
61	.55	-.66	.61	11.84
72	.66	-.71	.69	10.31
83	.77	-.77	.77	9.11
94	.88	-.83	.85	8.13
105	.99	-.90	.94	7.26
116	1.10	-.97	1.03	6.55
127	1.23	-1.03	1.13	5.92
138	1.37	-1.10	1.24	5.31
149	1.55	-1.17	1.36	4.72
160	1.76	-1.25	1.51	4.17
171	2.01	-1.34	1.68	3.65
182	2.32	-1.44	1.88	3.14
193	2.68	-1.56	2.12	2.68
204	3.05	-1.71	2.38	2.28
215	3.41	-1.86	2.64	1.96
226	3.74	-2.01	2.88	1.71
237	3.94	-2.13	3.03	1.57
248	3.94	-2.23	3.08	1.53
259	3.75	-2.35	3.05	1.56
271	3.44	-2.54	2.99	1.61
282	3.11	-2.92	3.01	1.59
293	2.86	-3.51	3.19	1.45
304	2.60	-4.60	3.60	1.17
315	2.34	-5.60	3.97	.96
327	2.19	-6.66	4.43	.76
339	1.72	-8.44	5.08	.54
351	1.18	-9.17	5.18	.51
364	.71	-10.20	5.45	.43
378	.06	-12.59	6.33	.23
392	-.57	-15.03	7.23	.08
403	-1.22	-17.45	8.12	-.04
424	-2.37	-20.93	9.28	-.16
428	-4.00	-25.23	10.62	-.27
436	-5.60	-28.88	11.64	-.33
444	-7.01	-31.68	12.34	-.37
452	-8.06	-33.54	12.74	-.39
460	-8.63	-34.45	12.91	-.40

THE MINIMUM MARGIN OF SAFETY IS -.40 IN ELEMENT 460

APPENDIX C

COMPOSITE UPPER DRAG BRACE FABRICATION AND ASSEMBLY PROCEDURE

In addition to absolute compliance with the fabrication and assembly procedures presented in detail herein, a complete manufacturing record is required. It shall include as a minimum the prepreg run and spool number, loaded weights, cure details, cured weights, machined weights, assembly weights, bond adhesive lot number, and assembly cure dimensions.

1.0 SIDE LINK FABRICATION

1.1 Main Web

1.1.1 Lay up two sets of broadgoods, Layers No. 1 and No. 2, with different ply orientations

Layer No. 1 $[0_3/\pm45/90]$

Layer No. 2 $[0_2/\pm45/90]$

Broadgoods for Layer No. 1 to fabricate four side links (two drag braces) should be:

0^{o} direction - 60 inches long

90^{o} direction - 24 inches wide (two 12-inch strips)

Broadgoods for Layer No. 2:

0^{o} direction - 40 inches long

90^{o} direction - 12 inches wide (one 12-inch strip)

1.1.2 Using fabrication aids (Web Prepreg Cutter, Drawing No. 83008S00768-003) for the "main web," cut shapes from the five and six-ply broadgoods:

Layer No. 1 (six-ply) - 8 each per side link or 32 for the two side braces

Layer No. 2 (five-ply) - 2 each per side link or 8 for the two side braces

1.1.3 Prepare tooling for preforming each "main web," Main Web Form Tool, Drawing No. 83008500767. Degrease each part with methylene chloride, scrub with Alconox detergent solution, dry and coat with Frekote. Bake in oven at 300^{o}F for 30 minutes.

1.1.4 Place the shaped broadgoods layers in the preform tool in the following stacking sequence: (Lay No. 1) (Lay No. 1)(Lay No. 2)(Lay No. 1)(Lay No. 1)(Lay No. 1)$_S$ (Lay No. 1)$_S$(Lay No. 2)$_S$(Lay No. 1)$_S$(Lay No. 1)$_S$, where the "S" connotates symmetry which requires only that the broadgoods shapes with "S" be placed inverted or with the 90^{o} ply down. Consolidate the 10 layers (58 plies) of prepreg with the forming tool. Stage at 200^{o}F. for 5 minutes under 100 psi pressure.

1.1.5 Remove the part and keep in a sealed bag, preferably at 0^{o}F, until the "main continuous racetrack" is prepared and ready for consolidation with the "main web."

1.2 Web Reinforcements - Large End - Inside (0.325 inch)

1.2.1 Lay up broadgoods for the drag brace large end, inside reinforcement (0.325 inch cross section). For each side link fabricate:

6 - Layer No. 1 = $[0_3/\pm45/90]$ - 6 plies

5 - Layer No. 2 = $[0_2/\pm45/90]$ - 5 plies

1 - Layer No. 3 = $[0_2]$ - 2 plies

To fabricate four side links:

24 - Layer No. 1

20 - Layer No. 2

4 - Layer No. 3

Broadgoods for four side links of Layer No. 1:

90^o direction - 24 inches wide or two each 12-inch strips

0^o direction - 18 inches long (same as fiber direction)

Broadgoods for four side links of Layer No. 2:

90^o direction - 24 inches wide or two each 12-inch strips

0^o direction - 12 inches long

1.2.2 Using fabrication aids (Web Prepreg Cutters) for the "web reinforcement," cut the required number of shapes from the prepared broadgoods.

1.2.3 Prepare tooling for preforming each of the inside reinforcements, the Main Web Form Tool. Ignore this requirement if the tooling has been previously prepared.

1.2.4 Place the shaped broadgoods layers in the preform tool in the following sequence: (Lay No. 1)(Lay No. 1)(Lay No. 2) (Lay No. 2)(Lay No. 2)(Lay No. 1)(Lay No. 1)(Lay No. $1)_S$ (Lay No. $1)_S$(Lay No. $2)_S$(Lay No. $2)_S$(Lay No. $3)_S$.

1.2.5 Remove the consolidated parts and keep in a sealed bag, preferably at 0^{o}F until the reinforcing racetracks are ready for consolidation of the two parts.

1.3 Web Reinforcement - Large End - Outside (0.495 inch)

1.3.1 Lay up broadgoods for the outside reinforcement, large end (0.495 inch cross section). For each side link fabricate:

10 - Layer No. 1 = $[0_3/\pm45/90]$ - 6 plies

7 - Layer No. 2 = $[0_2/\pm45/90]$ - 5 plies

To fabricate four side links, prepare:

40 - Layer No. 1

28 - Layer No. 2

Broadgoods dimensions for four side links:

Layer No. 1

90^{o} = 24 inches (2 each 12-inch strips)

0^{o} = 18 inches long (same as fiber direction)

1.3.2 Using fabrication aids (Web Prepreg Cutter) for the "web reinforcement" shape, cut the required number of shapes from the layered broadgoods.

1.3.3 Using the Main Web Form Tool, stack the cutout shapes in the following sequence: (Lay No. 1)(Lay No. 1) (Lay No. 2)(Lay No. 2)(Lay No. 2)(Lay No. 1)(Lay No. 1)$_S$ (Lay No. 1)$_S$(Lay No. 2)$_S$(Lay No. 2)$_S$(Lay No. 2)$_S$(Lay No. 1)$_S$ (Lay No. 1)(Lay No. 1)(Lay No. 2).

Total of 10 - Layer No. 1 at 6 plies/layer = 60 plies

7 - Layer No. 2 at 5 plies/layer = 35 plies

95 plies

Consolidate the 95 plies of prepreg with the preforming tool.

1.3.4 Remove the preformed part and store in a sealed bag, preferably at $0^{o}F$, until the reinforcing racetracks are available for consolidation of the two parts.

1.4 Web Reinforcements - Small End (0.41 inch)

1.4.1 The web reinforcing sections are identical for each side of the "main web" at the small or narrow end. Lay up broadgoods and cut out preform shapes for two web reinforcements per side link or eight web reinforcements for two complete drag brace assemblies being fabricated.

For each reinforcement fabricate:

8 - Layer No. 1 = $[0_3/\pm45/90]$

6 - Layer No. 2 = $[0_2/\pm45/90]$

Therefore, for each side link, 16 Layer No. 1 and 12 Layer No. 2 are required.

For four side links to fabricate two complete drag braces 64 Layer No. 1 and 48 Layer No. 2 are required.

First layer broadgoods dimensions:

90^{o} direction = 24 inches (two 12-inch strips)

0^{o} direction = 36 inches

Second layer broadgoods dimensions:

90^{o} direction = 24 inches

0^{o} direction - 36 inches

1.4.2 Using the Web Prepreg Cutter for the "web reinforcement" shape, cut the required number of shapes from the prepared broadgoods.

1.4.3 Using the Main Web Form Tool, preform the 0.410 inch cross section web reinforcements. Stack the shaped broadgoods in the preform tool in the following sequence: (Lay No. 1)(Lay No. 1)(Lay No. 2)(Lay No. 2)(Lay No. 2) (Lay No. 1)(Lay No. 1)(Lay No. 1)$_S$(Lay No. 1)$_S$(Lay No. 2)$_S$ (Lay No. 2)$_S$(Lay No. 2)$_S$(Lay No. 1)$_S$(Lay No. 1)$_S$

In summary,

8 - Layer No. 1 = 48 plies

6 - Layer No. 2 = 30 plies

78 plies = 0.41 inch

1.4.4 Remove the preformed parts and store in a sealed bag, preferably at 0°F, until the racetrack web reinforcements are ready for consolidation of the two shapes for each "web reinforcement." Label each part.

1.5 Side Link Main (Continuous) Racetrack Fabrication

1.5.1 The main racetrack is all 0° orientation, 0.70 inch (135 plies) thick, and 0.30 inch wide. To achieve this thickness, the racetrack will be mandrel wound in nine equal increments or 15 plies per increment. A special mandrel diameter must be used for each increment. Use precut spooled prepreg having a width of 0.30 inch for this racetrack. One "main racetrack" is required for each side link.

1.5.2 Prepare all mandrel racetrack tooling. Degrease with methylene chloride, scrub with Alconox detergent and Scotchbrite scrubbing pad. Spray a coat of Frekote 33 on the tooling. Bake for 30 minutes at 300°F.

1.5.3 Make one 15-ply racetrack with each of the mandrels of the Racetrack Mandrel Set (Drawing No. 83008S00771) as follows:

Item No.	Tool Identification	Diameter (in.)
8	-011	14.534
9	-013	14.688
10	-015	14.842
11	-017	14.996
12	-019	15.150
13	-021	15.304
14	-023	15.458
15	-025	15.612
16	-027	15.766

1.5.4 Preheat the mandrel tooling to 180°F prior to winding the 15-ply racetracks. Immediately wind on the preslit prepreg using the winding machine and hand guiding the material for placement. Use the revolution counter to determine the layed up plies.

1.5.5 Disassemble the tooling, remove the prepared racetrack and store in a sealed bag in the 0°F freezer until further assembly. Identify the parts as they are removed from the tooling.

1.6 Side Link Large End Inside Web Reinforcement Racetrack Fabrication (0.325 inch width)

1.6.1 The inside web reinforcing racetrack is also 0.70 inch thick and has a width of 0.325 inch for a total of 135 plies, all 0° orientation. Again, the racetrack will be formed from nine 15-ply increment racetracks, each having a different diameter tooling. Use precut prepreg spools of 0.325 inch width. The finished racetrack will be cut in half and one half will be used for each inside web

1.6.1 (cont.)

reinforcement which requires one per side link. Thus, one racetrack only will be required for each drag brace assembly fabricated or two racetracks for two drag brace assemblies.

1.6.2 Prepare mandrel tool as described in paragraph 1.5.2, above.

1.6.3 Make one 15-ply racetrack with each of the mandrels of the Racetrack Mandrel Set as follows:

Item No.	Tool Identification	Diameter (in.)
17	-029	9.930
18	-031	10.084
19	-033	10.238
20	-035	10,392
21	-037	10.546
22	-039	10.700
23	-041	10.854
24	-043	11.008
25	-045	11.162

1.6.4 Repeat operation 1.5.4 (preheat mandrel tooling).

1.6.5 Repeat operation 1.5.5 (disassemble tooling and store part). Identify parts as they are removed from the tooling.

1.7 Side Link - Large End - Outside Web Reinforcing Racetrack Fabrication

1.7.1 The outside web reinforcing racetrack is also 0.70 inch thick and has a width of 0.495 inch or a total of 135 plies, all 0^{o} orientation. Again, the racetrack will be formed from nine 15-ply increment racetracks, each having a different diameter and tooling. Use precut prepreg spools of 0.495 inch width. The finished racetrack will be cut in half and one half will be used for each side link or the one racetrack will be required for two side links.

1.7.2 Prepare mandrel tooling as described in operation 1.5.2.

1.7.3 Make one 15-ply racetrack on each of the following mandrels:

Item No.	Tool Identification	Diameter (in.)
35	-065	9.930
36	-067	10.084
37	-069	10.238
38	-071	10.392
39	-073	10.546
40	-075	10.700
41	-077	10.854
42	-079	11.008
43	-081	11.162

1.7.4 Repeat operation 1.5.4 (preheat mandrel tooling).

1.7.5 Repeat operation 1.5.5 (disassemble tooling and store parts). Identify each part as it is removed from the tooling.

1.8 Side Link - Small End - Inside and Outside Web Reinforcement Racetrack Fabrication

1.8.1 The inside and outside web reinforcing racetracks are both 0.410 inch wide at the small end and are 0.70 inch thick for a total of 135 plies, all 0^{o} orientation. Again, the racetrack will be formed from nine 15-ply increment racetracks, each having a slightly different diameter tooling. Use precut prepreg spools of 0.41 inch width. The finished racetrack will be cut in half, one-half each for the web supports at the narrow end of the side link. One racetrack will be required for each side link or two per drag brace assembly.

1.8.2 Prepare mandrel tooling as described in operation 1.5.2.

1.8.3 Make one 15-ply racetrack on each of the following mandrels:

Item No.	Tool Identification	Diameter (in.)
26	-047	9.930
27	-049	10.084
28	-051	10.238
29	-053	10.392
30	-055	10.546
31	-057	10.700
32	-059	10.854
33	-061	11.008
34	-063	11.162

1.8.4 Repeat operation 1.5.4 (preheat mandrel tooling).

1.8.5 Repeat operation 1.5.5 (disassemble tooling and store parts). Identify each part as it is removed from the tooling.

1.9 Assemble and Consolidate the "Main Web" and the "Main (Continuous) Racetrack"

1.9.1 Prepare the racetrack form tool, Drawing No. 83008S00766, for stretching and shaping the prepreg racetracks. Degrease with methylene chloride, wash in Alconox detergent solution and spray coat each of the different sized form wheels.

1.9.2 Using the various sets of form wheels, stretch each 15-ply racetrack (0.30 inch width) with the corresponding set of wheels as follows:

15-Ply Prepreg Racetrack No.	Form Wheel Dash No.
-011	-013
-013	-015
-015	-017
-017	-019
-019	-021
-021	-023
-023	-025
-025	-027
-027	-029

NOTE: Match up the smallest mandrel diameter formed prepreg with the smallest diameter set of form wheels and so on.

1.9.3 Once the 15-ply racetracks (0.30 inch width) are stretched, then carefully assemble the 135-ply racetrack from the racetrack increments. This requires that each smaller increment be placed within the next larger diameter increment racetrack.

1.9.4 Stretch the assembled increments on the stretching-forming tool using the -013 form wheels.

1.9.5 Prepare the main racetrack and web preform tool, Drawing No. 83008S00770-001. Degrease each part with methylene chloride, wash in Alconox detergent and spray with Frekote 33. Bake the coated tooling at 250°F for 30 minutes.

1.9.6 Place the "main web" in the assembled tooling. Locate the tooling plugs, Part No. -007, at each end of the web. Install the formed 135-ply racetrack around the web and plugs. Center this prepreg assembly within the tooling.

1.9.7 Force the components into position. Lightly compact with a soft hammer, if necessary. Put six plies of blue peel ply over the assembly and apply 100 psi pressure and 200°F temperature. Cool to 80°F. Remove pressure.

1.9.8 Remove the assembled prepreg parts from the tooling and store in preparation for assembly into a complete "side link."

1.10 Assemble and Consolidate the Reinforcing Web and the Reinforcing Racetracks for Each of the Web-Racetrack Combinations

1.10.1 Prepare the preforming and assembly tooling for the web reinforcement and sectioned racetrack consolidation, Drawing No. 83008S00769-001. Note that two bodies are

1.10.1 (cont.)

available for this tool. The -009 main body part will be used on the small or narrow end preforms (widths of 0.41 inch) and the -011 main body part will be used on the large or wide end preforms (widths of 0.325 and 0.495 inch).

1.10.2 Form stretch for each racetrack the increment 15-ply sections as described in Step 1.9.2. Again, use the -013 form wheels for the smallest diameter mandrel formed parts up through the -029 form wheels for the largest diameter mandrel formed parts.

1.10.3 Repeat operation 1.9.3 (assemble the racetrack increments).

1.10.4 Repeat Step 1.9.4 (stretch form the assembled racetrack components).

1.10.5 Carefully cut the completed racetrack preform in half. One-half will be used for each of the reinforcing webs. Label each half.

1.10.6 Install the web reinforcement in the prepared preforming tool. Locate the plug in the web section. Carefully place the half racetrack in position around the web and plug. Use the correct thickness plug for each particular web reinforcement being formed. The -013 plug is required for the 0.325 inch width web, the -014 plug for the 0.41 inch width web and the -015 plug for the 0.495 inch width web. Lightly hammer the parts into position if required. Heat may help. Two of the web reinforcements having a width of 0.41 inch, one each of the web reinforcements

1.10.6 (cont.)

having a width of 0.325 and 0.495 inch will be required for each side link fabricated or double these quantities for each drag brace being fabricated. Stage reinforcement web with six each plies of blue peel and 100 psi pressure at 200^{o}F for 5 minutes. Cool to 80^{o}F. Turn off pressure.

1.11 Assemble the preforms in the side link mold and perform a cure cycle.

1.11.1 Prepare the side link mold tooling, Drawing No. 83008S00764-001. Degrease, scrub each part in an Alconox detergent solution, spray each part with Frekote 33 and bake at 250^{o}F for 30 minutes.

1.11.2 Install the preformed parts into the assembled tooling. Be especially careful to install the preformed parts in their correct order. Make sure that all "O" rings are in position as assembly progresses. With the lower mold section on the table and the female cavity mold in position, install the 0.495 inch thick web reinforcement in the mold at the lower end of the mold, the end with the surface closest to the table. Install one of the 0.41 inch thick web reinforcements at the opposite end of the mold. Install the main web and racetrack preform on the tooling noting the correct placement in regard to the preformed shape and the corresponding surfaces of the cavity mold. Install the web reinforcement preform with a cross section of 0.325 at the lower end of the mold,

1.11.2 (cont.)

the end with its surface closest to the table. Install the remaining 0.41 inch width preform at the opposite end. The 0.41 inch width web reinforcements must be located on the same pin. Install the upper mold section, Part No. -009, onto the mold assembly. Place the assembly in the large platen press and cure the part using the 3501-5 press cure cycle:

Put on 50 tons with 0.020 inch shims in place.

Heat to 250°F for 1 hour. Remove shims.

Heat to 300°F for 30 minutes.

Heat to 350°F for 1 hour.

Take out pins at 350°F.

Remove part at temperature above 300°F.

1.11.3 Remove the mold assembly from the press. Remove the female cavity with the part from the mold body. Determine the direction of taper within the female mold. Place the part and female mold in the press and support it off the platen surface with standoffs. The taper in the mold must be positioned with the wider cavity cross section down. The part is then pressed out with a male plug placed on the finished composite side link part. Heat on the mold cavity may have to be increased to an optimum 300°F temperature for maximum clearance around the finished part before pressing it out of the mold. Once the part is extracted, inspect for obvious defects or damage. Clean the part in preparation for machining.

2.0 SHEAR WEB FABRICATION

2.1 The "shear web" will be fabricated using a steel female mold and an RTV-silicone rubber compaction tool. The shear web will have a wall thickness of 0.12 inch and will taper from one end to the other both in vertical section and horizontal section. Twenty-four plies of precut layers will be required.

2.1.1 Lay up required broadgoods:

4 - Layer No. 1 per shear web per drag brace where Layer No. 1 is $[0_3, \pm 45, 90]$ per shear web:

0_3, ± 45, 90, 0_3, ± 45, 90, ∓ 45, 0_3, 90, ∓ 45, 0_3.

Broadgoods dimensions:

90° direction - 24 inches or 2 each 12-inch wide strips

0° direction - 36 inches

2.1.2 Cut from the broadgoods four shear web shapes 15.44 inches long and 7.0 inches wide on one end by 5.25 inches wide on the other end. Taper each side symmetrically. Three shapes can be cut from each 18-inch length along the 0° direction.

2.1.3 Fabricate an RTV-silicone rubber compaction tool from the metal tooling, Spreader Mold, Drawing No. 83008S00773-001. First, line the metal mold forming surfaces with a complete layer of Teflon tape material. Carefully form a layer of 1/8-inch Thermo Stable Sheet Wax No. 266. Smooth wrinkles and nonuniform surfaces. Use a heat gun if needed. Mix a small batch of RTV-silicone rubber,

2.1.3 (cont.)

Dow-Corning 97-072. Allow it to evacuate in the vacuum oven for 30 minutes to remove entrapped air. Pour the mixed rubber in the mold assembly with the two end plates installed. Allow to cure overnight. Remove the rubber tool from the mold cavity and post cure the rubber at 250°F for four hours.

2.1.4 Clean the metal tool. Degrease with methylene chloride and scrub the parts with Alconox detergent solution and a Scotchbrite pad. Allow to dry. Spray each metal part with a coat of Frekote 33. Bake at 250°F for 30 minutes.

2.1.5 Stack the prepared broadgoods layers in the mold assembly in the following order: (Lay No. 1)(Lay No. 1)(Lay No. 1)$_S$ (Lay No. 1)$_S$.

2.1.6 Place the silicone rubber compaction tool in the metal mold without disturbing the layed up prepreg. Trim away any protruding prepreg. Install both ends and the lid for the mold box.

2.1.7 Final cure the assembly. Using the large Hydrolair 100-ton press, a press cure cycle for 3501-5 may be used.

2.1.8 Remove the cured part from the mold box. Clean the part in preparation for machining to size. Once the part is machined, take an accurate weight and record.

3.0 <u>SMALL END "U" SHAPED GUSSET FABRICATION</u>

3.1 The small end gusset will be fabricated essentially as the "shear web" was fabricated with a rubber compaction tool and a two-piece female mold, the End Gusset Mold (Drawing No. 8300800775-001.)

3.1.1 Lay up required broadgoods:

Orientation required: $[0_2/\pm45/90]$ = Layer No. 2

Need 6 layers or 30 plies for a thickness of 0.150 inch.

Broadgoods dimensions: For plies 6 inches long (0^o direction) x 3.40 inches wide

90^o direction - 12 inches long

0^o direction - 12 inches long

3.1.2 Cut from the broadgoods six rectangular shapes 6 inches long by 3.4 inches wide with the 0^o orientation along the channel. Stack the shapes in the following order: (Lay 2)(Lay 2)(Lay 2)(Lay $2)_S$(Lay $2)_S$(Lay $2)_S$, for a total of six each Layer No. 2 of five plies per layer for a total of 30 plies.

3.1.3 Cast an RTV-silicone rubber compaction tool from the metal tooling using the same technique described in operation 2.1.3. Use 1/8-inch thick aluminum end plates "C"-clamped to the ends to form a cavity.

3.1.4 Repeat clean-up and tooling preparation procedure.

3.1.5 Install the layed up broadgoods in the prepared mold in the sequence described in 3.1.2.

3.1.6 Line the layed up prepreg with one layer of TX 1040 release film and seven layers of Mochburg bleed paper. Install the silicone rubber compaction tool in the tooling and stage in the large press for 30 minutes at 250^oF part temperature. Remove the tooling from the press, remove the compaction tool and the release, and bleed the films. Reinstall the compaction tool.

3.1.7 Place the mold assembly in the large press. Run a cure cycle on the gusset part:

1 hour at 250^{o}F

30 minutes at 300^{o}F

1 hour at 350^{o}F

Use the press for contact pressure only. "C" clamps must be used to restrain the end plates.

3.1.8 Remove cured part from the mold tooling. Clean and weigh. Prepare for shipment for machining to print.

4.0 LARGE END "U" SHAPED GUSSET FABRICATION

4.1 Repeat all the steps used to fabricate the small end gusset, paragraph 3.0 in its entirety. The prepreg required will be larger in dimensions:

0^{o} direction - 12 inches long, 18 (0^{o}) x 12 (90^{o})

90^{o} direction - 24 inches wide or two 12-inch wide strips

Cut six each Layer No. 2, 4.75 inches wide x 6.0 inches long.

5.0 FLAT GUSSET FABRICATION

5.1 Fabricate a flat panel, 0.12 inch thick or 24 plies using the orientation of Layer No. 1: $[0_3/\pm45/90]$. Layup sequence: (Lay No. 1)(Lay No. 1)(Lay No. 1)$_S$(Lay No. 1)$_S$.

Plate size - 24 inches x 25 inches (enough for three assemblies).

Identify the 0^{o} orientation by laying bottom ply along the 25-inch direction. Use the closed mold tooling.

5.2 Curing cycle - large Hydrolair press:

Increase temperature to 250^{o}F.

Begin to pressurize at 225^{o}F. Apply slowly until 0.020 shims are contacted.

Hold one hour at 250^{o}F.

5.2 (cont.)

Pull shims. Increase pressure until shoulders are in contact.

Hold thirty minutes at 300°F.

Hold one hour at 350°F.

5.3 Identify plate orientation. Remove from mold. Clean in preparation for machining.

6.0 <u>BOND SIDE LINK BUSHINGS</u>

6.1 Prepare the Insert Bond Fixture, Drawing No. 83008S00774. Degrease with methylene chloride, wash with Alconox detergent solution, allow to dry and apply a coat of Frekote 33 release agent to all parts and bushings of the tooling.

6.2 Dry run fit the proper bushings for each of the two side braces to be bonded. The order of assembly is important as well as the correct placement of the bushings and side link. Place bushing part No. -20 on the high end of the tool with the 45° shoulder <u>UP</u> and the 0.90 inch hole aligned towards the center of the main web. Place the bushing part No. -40 at the other end of the tool with the 30° shoulder <u>UP</u>. (Shoulder angles are measured from the bore centerline.)

6.3 Place the tool bushings in the correct side link inserts on the bonding tool. Tool bushings part No. -011 go inside link bushing part No. -20, at the high end. Tool bushing part No. -025 goes inside link bushing part No. -40.

6.4 Slide a finish machined side link on the tooling. Note that the drilled out end must go on the high end of the tooling. Select proper size bondline wires and tape in place.

6.5 Install washers and bolts in the fixture and tighten. Check for proper fit.

6.6 Disassemble the tooling and side link parts. Maintain a separation between parts for each end.

6.7 Prepare the side brace and side brace bushings for bonding. Lightly sand the side link bore holes with 220 grit silicone carbide abrasive paper. Wipe clean with methylene chloride. Do not touch these prepared surfaces. The side brace bushings must be degreased with methylene chloride, grit blasted on the bonding surfaces only and stored in sealed plastic bags prior to the bonding operation. Again, degrease the bushings and perform a Pasa-Jell 107 treatment on the bonding surfaces only. Allow to dry and do not touch the prepared surfaces. Degrease the bond-line wires.

6.8 Prepare a batch of EA 934 adhesive. Mix in the ratio of 76 parts by weight of Part A and 25.1 parts by weight of Part B. Approximately 50 grams total or 37.5 grams of Part A and 12.5 grams of Part B should be adequate per side link. Mix components for 10 minutes. Use the adhesive within 45 to 60 minutes after combining the ingredients.

6.9 Tape bondline wires to composite part. Apply the adhesive to the side link bores and the side link bushing bonding surfaces with a tongue depressor. Spread the glue on in an even, uniform film. Work the surfaces for complete wetting.

6.10 Install the large end side link bushing (Part No. -20) in the side link bore. Do not twist the bushing during installation. Center and align the drilled lubrication orifices. Clean excess glue from both sides.

6.11 Install the 0.075-inch diameter by one inch long pin in the drilled lubrication orifice of the large end of the side link and side link bushing. This pin must be thoroughly cleaned and coated before installation. Allow the pin to protrude into the bushing bore.

6.12 Install the small end side link bushing (Part No. -40). Clean both sides. Note again that the correct shoulder of each bushing is in the side link as directed in paragraph 6.3.

6.13 Place the side link with the correct side up in the bonding tool. Install the tooling bushings as noted in 6.3.

6.14 Install the shoulder bolts and washers on the assembly and tighten.

6.15 Allow the side link assembly to cure for a minimum of eight hours.

6.16 Remove the side link from the tooling. Remove the 0.075 inch pin from the bore. Allow room temperature cure for an additional 12 hours before finish clean-up. Clip all bondline wires flush with bushings. Identify the part as "side link A" and the number of its fabrication, #1, #2, etc.

6.17 Repeat operations 6.2 through 6.16 for "side link B." The high side tooling bushing (Part No. -009) is used with side link bushing Part No. -10. The 45° shoulder must be <u>UP</u>. The low side tooling bushing must be Part No. -013 and the matching side bushing Part No. -30. The 45° shoulder of the link bushing must be <u>UP</u>.

7.0 <u>BOND COMPLETE UPPER DRAG BRACE ASSEMBLY</u>

7.1 Physically inspect the component parts which are to be bonded. Record fabrication numbers and weights of those components having numbers. Weigh the remaining parts. Check side links A and B for correct bushing orientation per fabrication drawing.

7.2 Prepare the assembly bonding fixture (Drawing No. 83008500777-001) for use. Degrease with methylene chloride, wash down with Alconox solution, and allow parts to dry. Spray a coat of Frekote 33 release agent. Bake in oven to 250°F for 1 hour.

7.3 Dry run fit the assembly components in the bonding fixture.

7.3.1 Place side link A over the pins of the bonding fixture. The large end (lubrication orifice end) should slide over the tall side of the fixture. The 60° angle of the small end bushing should be UP and the 60° angle of the large end bushing should be UP.

7.3.2 Install the inner and outer sleeves of the tooling (Part Nos. -005 and -007) on the small end of the tooling. The stepped outer sleeve must be assembled above the cylindrical shaped inner sleeve. Install the tapered pin. Measure top to bottom of the -005 and -007 sleeves for correct total cross section. This measurement must be 1.500 +0.002 inch. Disassemble, clean and recheck this dimension if not in tolerance.

7.3.3 Install the inner and outer sleeves of the tooling (Part Nos. -019 and -011) on the large end of the tooling. The cylindrical shaped sleeve is installed above the stepped sleeve on the large end. Install the tapered pin. Measure the assembled sleeve cross section. This measurement must be 3.357 +0.002 inch.

7.3.4 Position the main shear web in the bonding fixtures. The channel side of the shear web must face the stand support. The lower side of the shear web should conform to the side link A cross-sectional shape.

7.3.5 Install the upper side link, side link B. The drilled lubrication orifice end of the side link must be installed on the tall end of the fixture. Move the shear web as necessary to conform with both side links.

7.3.6 Install the washers and bolts in the alignment pins. Torque each to 50 in.-lbs. "C"-clamp the web in position. Note any large gaps or interference fits. Lightly pencil the web outline on the side link web contact areas. Select the proper size bondline wires.

7.3.7 Disassemble the tooling and drag brace components, except do not remove the lower side link or sleeves. Prepare components for bonding. Lightly sand the web and side brace contact areas. Wipe down with clean rags and methylene chloride. Do not touch these prepared surfaces. Degrease bondline wires.

7.3.8 Prepare a batch of EA 934 adhesive. Mix in the ratio of 76 parts by weight of Part A and 25.1 parts by weight of Part B. Approximately 101 grams total, or 25 grams of Part B and 76 grams of Part A, should be an adequate amount.

7.3.9 Tape bondline wires in place. Apply the adhesive to the contact areas of the two side links and the shear web. Spread the glue on in an even, uniform film. Work the surfaces for complete wetting.

7.3.10 Reassemble the components in the bonding fixture. Repeat steps 7.3.4 through 7.3.6. Note the correct positions of each component.

7.3.11 Create a 1/2-inch radius fillet of glue along the back side of the shear web. Create a fillet of glue along the channel side of the web contact.

7.3.12 Clean excess glue with methylene chloride-dampened clean rags. Allow the assembly to cure for a minimum of eight hours. Remove from the tool and clean excess glue.

7.4 Install the "U" shaped gussets and flat shaped gussets.

7.4.1 Place the drag brace on a clean, flat surface with the channel side of the shear web up. Granite table is preferred.

7.4.2 Trial fit each of the "U" shaped gussets and correctly position per Drawing No. 83008S00759. Also fit the flat gusset shapes on the channel side of the shear web. Select proper size bondline wires.

7.4.3 When the fit is satisfactory, lightly sand the graphite/epoxy parts at all points of contact. Clean with methylene chloride-dampened rags. Do not touch the prepared surfaces. Tape the bondline wires in place.

7.4.4 Mix a 100-gram batch of EA 934 and apply to the contact points. Place each of the gusset components in their correct locations. Create fillets along all of the contact edges. Clean with methylene chloride-dampened rags. Allow adhesive to cure for a minimum of 8 hours.

7.4.5 Turn the assembly over on the flat table and repeat steps 7.4.2 through 7.4.4 for the remaining flat gusset shapes. Use standard set-up techniques for locating the gussets correctly. Clip bondline wires flush with composite.

7.5 Clean the entire upper drag brace assembly. Obtain a final finished weight and record.

APPENDIX D

COMPOSITE UPPER DRAG BRACE RADIOGRAPHIC INSPECTION PROCEDURE

1.0 SCOPE

This procedure outlines the radiographic inspection of F-15 composite upper drag braces. The inspections shall be performed at the molded level, at a pre-final assembly level with side links bonded, and at the final assembly level.

2.0 QUALIFICATIONS

The personnel used to perform this inspection shall be certified in accordance with MIL-STD-410D.

3.0 EQUIPMENT

3.1 X-Ray Generators

Norelco MG 150KV

Inherent filtration - 3mm Be or Seifert Inherent filtration - Be

2.5mm focus (12 ma at 150 KVP)

3.2 Kodak Model B X-Omat film processor

3.3 MacBeth densitometer model TD100

4.0 EXAMINATION TECHNIQUES

4.1 Edge view - 80 KU - 10MA - 40 SEC A&M Redipak

4.2 Edge at holes on end - 60KU - 6MA - 58 SEC - M&T Redipak

4.3 Flat thin areas - 50KU - 6MA - 17 SEC M Redipak

4.4 Flat thick ends - 50KU - 6MA - 40 SEC M&T Redipak

4.5 Shoot all films at 48-inc FFD.

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5.0 INSPECTION PROCEDURE

5.1 Inspections shall be performed with a 150 KU beryllium window X-ray tube and with Eastman-Kodak type M ready-pack film (or equivalent). Film densities shall be from 2.0 to 3.5 H&D units in areas to be interpreted.

5.2 One inspection shall be performed at the molded level. Three exposures shall be taken as follows:

View 1 - The X-ray beam centerline shall be aligned with the centerline of the forward brace hole with the part laying flat on the film.

View 2 - The X-ray beam centerline shall be aligned with the centerline of the aft brace hole with the part laying flat on the film.

View 3 - The X-ray beam centerline shall be centered on the center of the brace with the brace on edge. Two films shall be used to provide overlap and full coverage of the part.

5.3 One inspection shall be performed with the inserts bonded in place. The bond shall be inspected every 45^{0} in a tangential mode. Up to four parts may be exposed on a film at one time.

5.4 One inspection shall be performed at the final assembly level as follows:

View 1 - The X-ray beam shall be centered on the assembled brace with beam centerline normal to the surface of the spreader web.

View 2 - The X-ray beam shall be angled 30^{0} to the left of View 1. Exposure shall be taken to check two of the gusset-to-spreader web bonds on each gusset.

View 3 - The X-ray beam shall be angled 30^{o} to the right of View 1 to check the remaining gusset bonds.

View 4 - Spreader Web. One exposure shall be taken with the X-ray beam centered on the web with the web laying flat on the film.

APPENDIX E

COMPOSITE UPPER DRAG BRACE ULTRASONIC INSPECTION PROCEDURE

1.0 SCOPE

This procedure outlines the ultrasonic inspection of F-15 composite upper drag braces. The inspection would be performed at the molded level.

2.0 QUALIFICATIONS

The personnel performing this operation shall be thoroughly knowledgeable of ultrasonic principle and certifiable to SNT-TC-1A requirements.

3.0 EQUIPMENT

3.1 Sonsray Model 5 Instrument

3.2 Automation Industries 5.0 and 10.0 MHz Contact Transducers

3.3 Coaxial Cable

3.4 Couplant

3.5 Special Calibration Block of Graphite

4.0 INSPECTION PROCEDURE

4.1 Calibration of Instrument

4.1.1 *The Sonsray will be set up using the graphite calibration* block. Using total thickness of the block, the cathode ray tube (CRT) display will be adjusted for multiple back reflection response. Note the instrument sensitivity control setting.

4.1.2 Without changing the sensitivity, position the transducer over the mid-section of the brace and note multiple back reflections. Check at two other locations to ensure same response. If reflections are not the same as for the calibration block, the gain should be changed to obtain similar response to the block.

4.1.3 Position the transducer over the 3/64 inch flat bottom holes of the calibration block with the holes at 50 and 100 percent of the part path. Adjust the sensitivity to ensure that the CRT response of the least responsive flat bottom hole is 2:1 over the noise level experienced from the part. Note the linear position and amplitude for reference during the initial scanning.

4.1.4 Move the transducer over the calibration block and observe the response of the signal amplitude from the flat bottom hole. Maximize the signal. Mark and move the transducer laterally until the response signal is reduced 50 percent. Mark and repeat in lateral directions each side of the position where the maximum response is experienced at scan sensitivity. Measure the distances and determine the transducer effective beam diameter.

4.2 Test Procedure

4.2.1 Scan 100 percent of the inner flat portion of the brace manually with an overlap of at least 25 percent of the effective beam diameter. Turn the brace over and repeat the scan on the opposite side.

4.2.2 During scanning, be alert to all indications, including indications less than rejectable levels, which affect back reflection multiples or response amplitudes. Maximize the response of individual indications equal to 50 percent of the rejection level.

4.2.3 Mark for evaluation to the calibration block all indications equal to the minimum flat bottom hole size or areas where multiples or response of back reflection is affected and indications with length or multiple indications.

4.2.4 Evaluate discontinuities in accordance with established criteria. Indications in excess of the established quality level will be plotted, reported with the dimensions affected and submitted for review.

4.2.5 Repeat the above procedure for the flat portions of the sides of the brace, including the buildup areas. Note that buildup areas may require a lower frequency transducer. Since the main purpose of inspection is to check for delaminations, all inspections should be perpendicular to plies.

APPENDIX F

COMPOSITE UPPER DRAG BRACE

TEST PLAN

This Test Plan was prepared to verify the suitability of a composite upper drag brace for use on the F-15 airplane. The test procedure specified herein was conducted until brace failure occurred, as reported in Section V of this report.

1.0 PURPOSE OF TEST

1.1 The purpose of this test program is to provide data to substantiate that a landing gear upper drag brace fabricated from a graphite-epoxy composite material is suitable for use on the F-15 airplane.

2.0 DESCRIPTION OF TEST ARTICLE

2.1 The test article will be an upper drag brace assembly fabricated from graphite-epoxy composite materials.

2.2 This plan proposes to conduct all testing on one (1) upper drag brace assembly.

3.0 TEST REQUIREMENTS AND SUCCESS CRITERIA

3.1 The test program will consist of the following tests conducted in the sequence shown:

Test	Success Criteria
a. Proof test to a tension load of 102,400 pounds.	a. No evidence of cracking, delamination, permanent set, or failure.

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b. Fatigue test to a load spectrum totaling 14,400 cycles representative of six (6) lifetimes for the brace.	b. No failure.
c. Static test to 153,600 pounds tension load and 156,300 pounds compression load.	c. No failure. Existence of cracks, delamination and permanent set is permitted.

4.0 TEST SETUP

4.1 The test unit will be set up as shown in Figure F-1 using fixture number T-72576 for all testing. The composite brace will be tested as a component of the F-15 drag brace assembly, consisting of the lower drag brace, lower jury link, and attaching hardware using production landing gear parts available from the drop test gear. These parts are:

a. MCAIR P/N 68A410792-1001, Lower Drag Brace Assembly (CPC P/N 1915-72).

b. MCAIR P/N 68A410795-1001, Lower Jury Link Assembly (CPC P/N 1915-75).

c. MCAIR P/N 68A410637-1001, Drag Brace Bolt Assembly (CPC P/N 1849A37).

d. MCAIR P/N 68A410601-1001, Bellcrank Assembly (CPC P/N 1849B1).

e. MCAIR P/N 68A410755-2005, Drag Brace Apex Pin (CPC P/N 1849A118B).

f. MCAIR P/N 68A410764-2001, Jury Brace Apex Pin (CPC P/N 1849A110).

g. MCAIR P/N 68A411 Bolt (Upper Drag Brace to Airframe Connection).

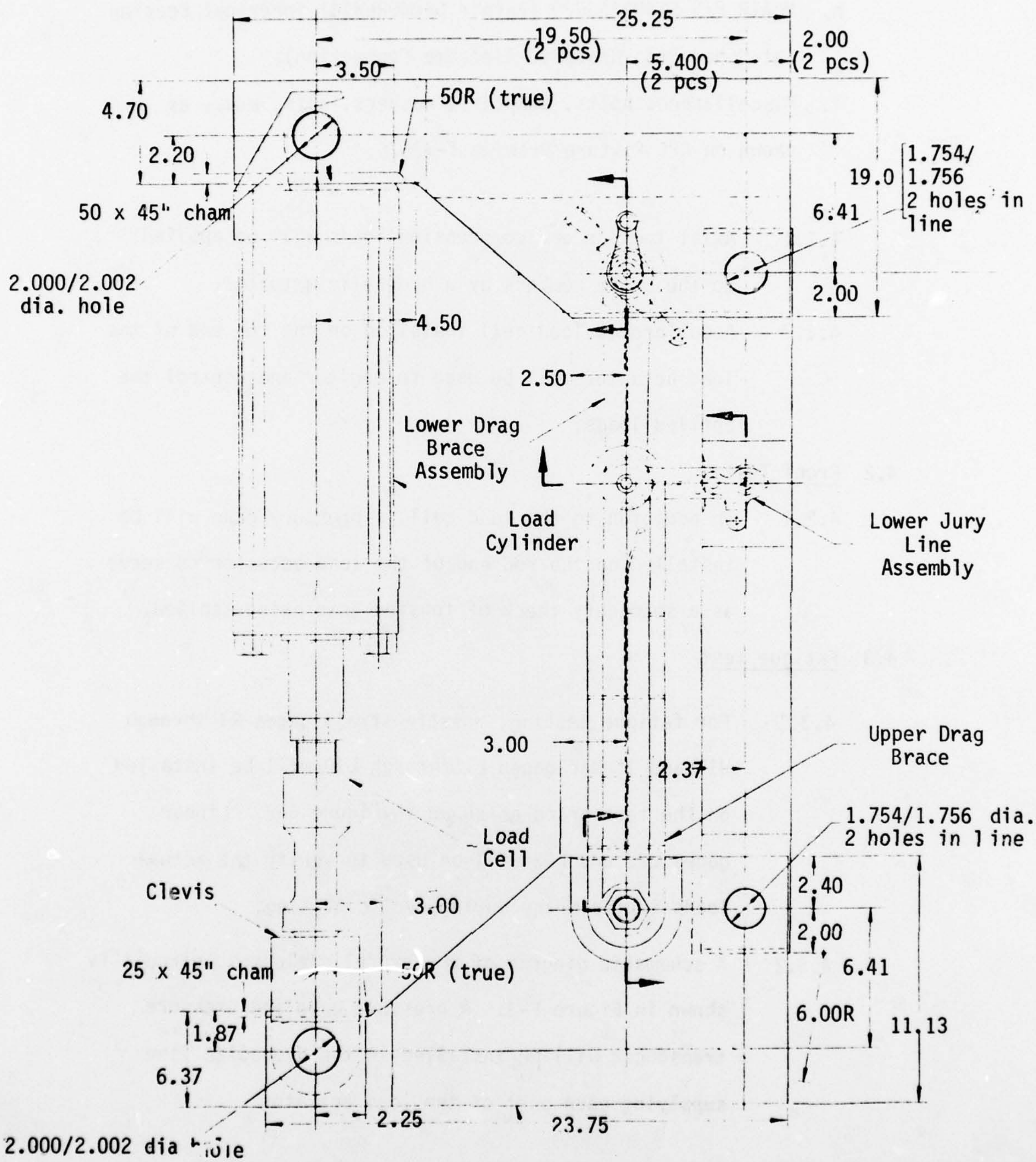


FIGURE F-1
Fatigue and Static Test Fixture

h. MCAIR P/N ST4M123GR20 (Fafnir SBU40RLH74) Spherical Bearing (at Upper Drag Brace to Airframe Connection).

i. Miscellaneous bolts, adapters, washers, nuts, etc., as shown on CPC Fixture Drawing T-72576.

4.1.1 Axial tension and compression loads will be applied to the brace members by a hydraulic actuator.

4.1.2 A calibrated load cell installed on the rod end of the load actuator will be used to monitor and control the applied loads.

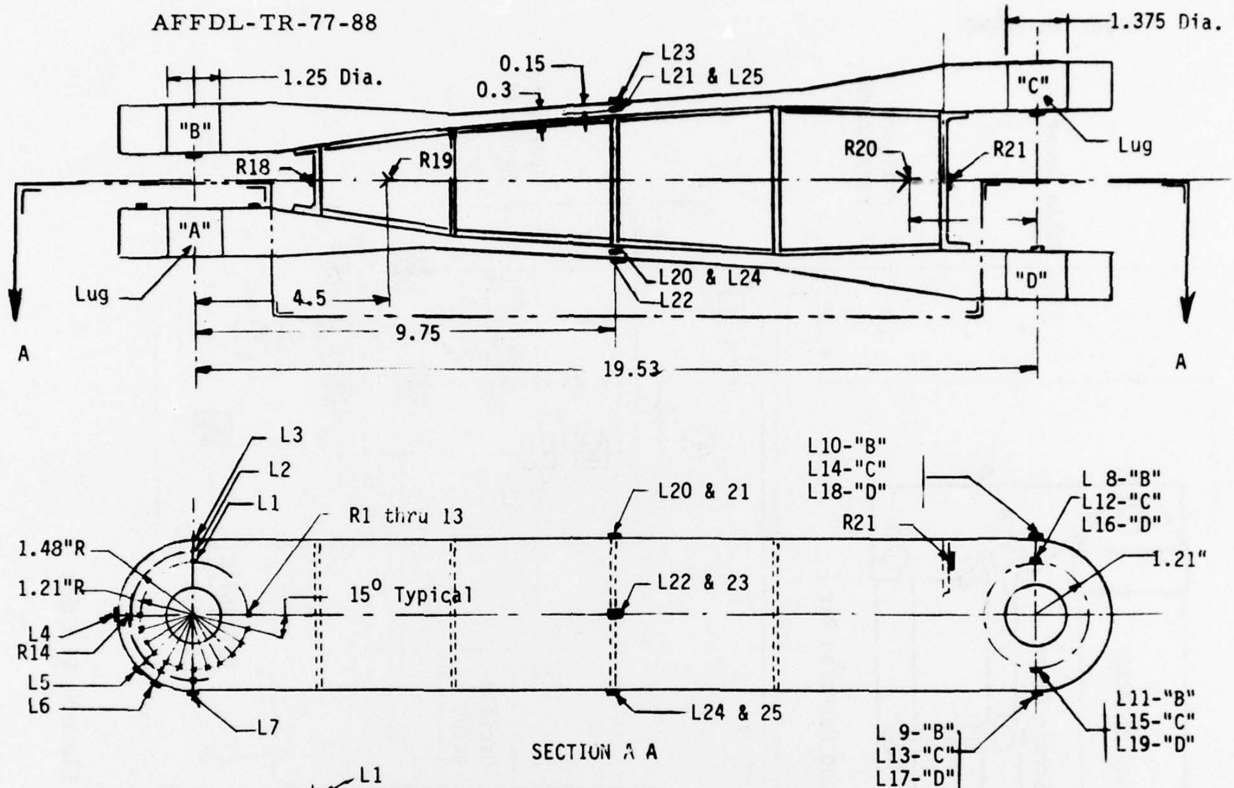
4.2 <u>Proof Test</u>

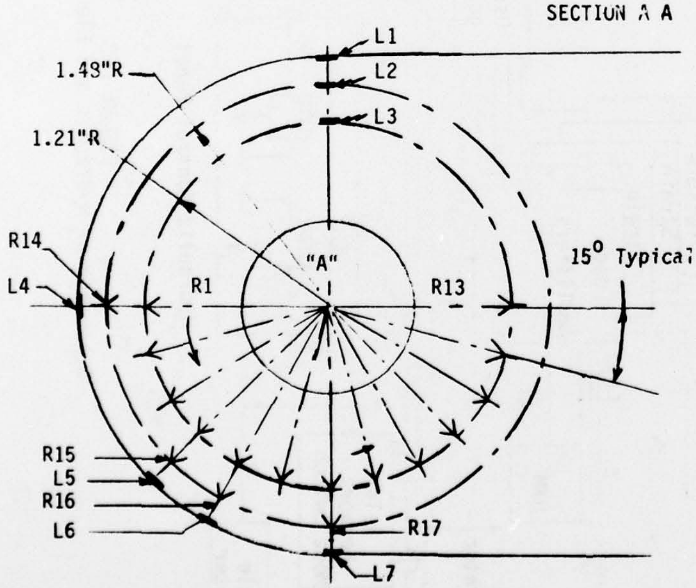
4.2.1 In addition to the load cell, a pressure gage will be installed on the rod end of the load actuator to serve as a secondary check of tension load being applied.

4.3 <u>Fatigue Test</u>

4.3.1 For fatigue testing, rosette strain gages R1 through R17 and linear gages L1 through L10 will be installed on the test brace as shown in Figure F-2. Linear gages L22 and L23 will be used to verify the actual loads in the brace during cyclic testing.

4.3.2 A schematic diagram of the hydralic/electric circuit is shown in Figure F-3. A pressure gage and pressure transducer will be installed in the hydraulic line supplying each port of the load actuator.





Gage No. (Rosettes)	Location	Gage No. (Linear)	Location
R 1	Lug A	L 1	Lug A 1.21R
2	at	2	1.48R
3	1.21R	3	1.75R
4		4	1.75R
5		5	1.75R
6		6	1.75R
7		7	Lug A 1.75R
8		8	Lug B 1.21R
9		9	1.21R
10		10	1.75R
11		11	Lug B 1.75R
12		12	Lug C 1.21R
13		13	1.21R
14	Lug A	14	1.75R
15	at	15	Lug C 1.75R
16	1.48R	16	Lug D 1.21R
17		17	1.21R
18	Gussett @ 2.85	18	Lug D 1.75R
19	Web @ 4.50	19	Lug D 1.75R
20	Web @ 3.00	20	Mid-Section 1.75R
21	Gussett @ 2.16	21	
		22	
		23	
		24	Mid-
		25	Section

FIGURE F-2
Strain Gage Locations

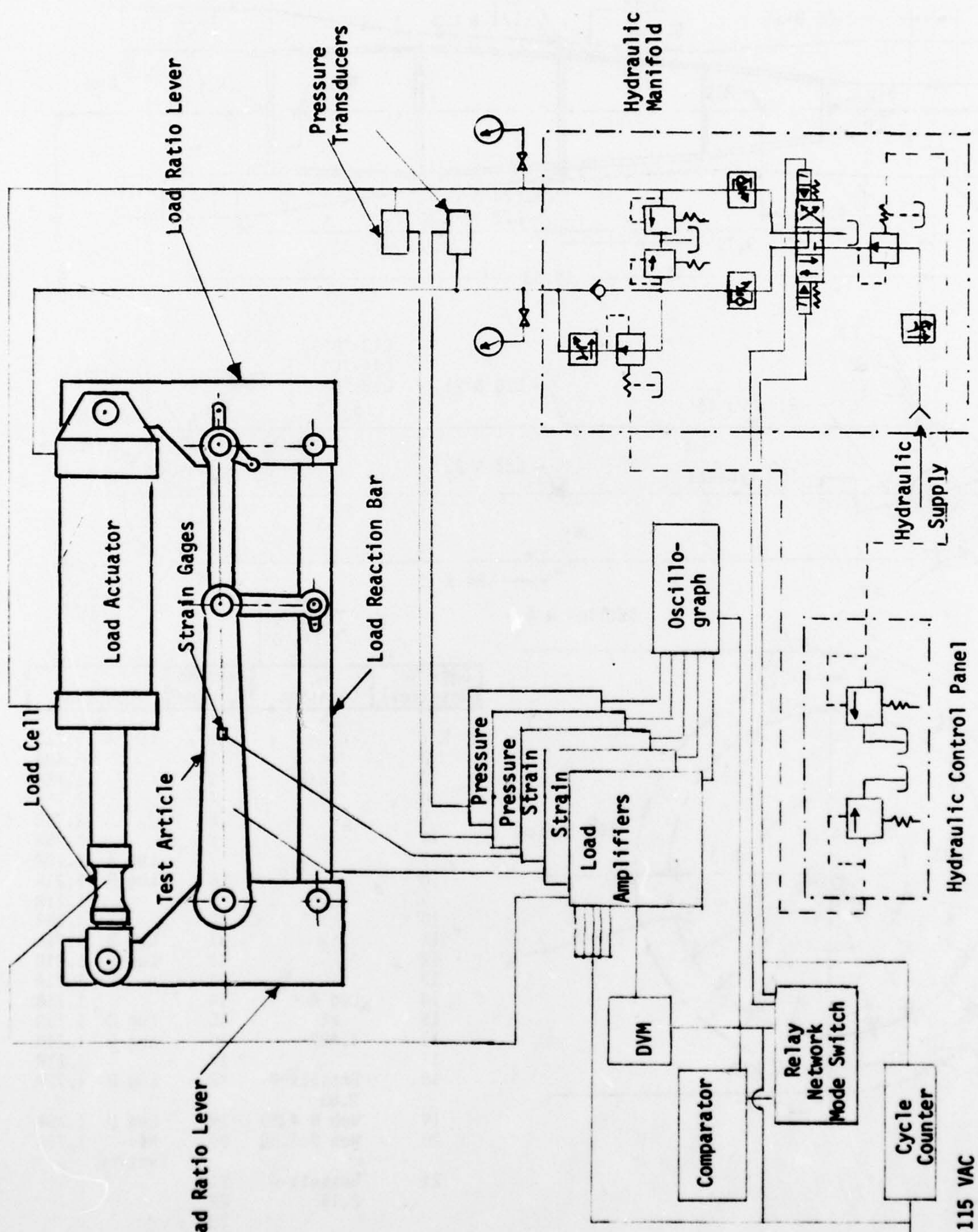


FIGURE F-3
Schematic of Hydraulic and Electric Circuits

4.3.3 The load applied by the hydraulic actuator will be controlled by a semiautomatic load control system. The load control system consists of a comparator circuit and manually adjusted pressure regulators. The compression/tension load combination is preset on the comparator unit and the pressure regulators are adjusted to achieve these loads. When the compression load is achieved, a four-way valve is shuttled and the actuator is pressurized to achieve the tension load. When the tension load is achieved, the comparator causes the four-way valve to shuttle to pressurize the actuator until the compression load is again achieved. The process repeats until the required cycles have been applied.

4.3.4 At appropriate intervals while cycling, output signals from the load cell, strain gages (L22 and L23), and pressure transducers will be recorded against time using a suitable recording oscillograph. In addition, the output signal from the load cell will be conditioned and fed into a digital voltmeter (DVM) to visually monitor applied loads during setup and as needed throughout the testing. An electric counter will be used to summate the total cycles applied for each step.

4.4 Static Test

4.4.1 For static testing, the test brace will be strain gaged at selected points to obtain design verification. The number and location of the strain gages, determined by analysis, are shown in Figure F-2. All of the strain

gages shown in Figure F-2, including those specified for fatigue testing, will be utilized for static testing.

4.4.2 The loads applied by the hydraulic actuator will be controlled by manually adjusting applied pressure. The load magnitude will be measured by the load cell in line with the hydraulic actuator. The load will be monitored visually on a digital voltmeter (DVM).

4.4.3 Strain gage data and applied load will be recorded using a suitable multi-channel strain recording instrument.

5.0 <u>TEST PROCEDURE</u>

5.1 Before conducting any tests, the part will be inspected to blueprint dimensions and the actual values recorded.

5.1.1 Test records will be maintained and verified by CPC and DCASR Inspection for all testing conducted.

5.2 Proof Test

5.2.1 With the test article installed in the test fixture, a proof load in tension of 102,400 pounds (plus 5%, minus 0) will be applied and maintained for a minimum of three (3) seconds, then released.

5.2.2 After application of the proof load, a check of the following dimensions will be made for comparison with those taken before test:

a. Diameters of all load bearing lug holds indicating limits of roundness.

b. Length of brace between centerlines of end lug holes.

The brace will also be visually inspected to verify that no evidence of cracking, delamination, permanent set or failure exists.

5.3 Fatigue Test

5.3.1 The test article will be installed in Fixture T-72576, as shown in Figure F-1.

5.3.2 While applying the first two (2) cycles of fatigue loads; i.e., Block 1, Step 1, Conditions 500 and 501 (ref. Table F-I), it is planned to obtain some "static test" data as follows:

5.3.2.1 Strain gages R1 through R17 and L1 through L19 (reference Figure F-2) will be connected to a suitable multi-channel strain recording instrument. The output of the load cell will also be fed into the recording instrument.

5.3.2.2 The fatigue tension load of 72,640 pounds for Condition 500 will be applied manually, stopping at 25% increments to record strain values from all strain gages and also the applied load as measured by the load cell. When releasing the load to zero, similar data will be recorded at approximately the same load levels as for the increasing load.

5.3.2.3 The procedure will be repeated for the application of the fatigue compression load of 57,345 pounds for Condition 501.

TABLE F-1

F-15 DRAG BRACE FATIGUE SPECTRUM

Step	Condition	Load (KIPS)	Cycles Per Life	Cycles For 6 Lives
1	500	72.640	2	12
	501	-57.345		
2	502	55.598	2	12
	503	-38.999		
3	504	58.103	5	30
	505	-48.507		
4	506	44.552	5	30
	507	-28.664		
5	508	46.383	8	48
	509	-36.863		
6	510	37.104	8	48
	511	-22.424		
7	512	37.463	170	1,020
	513	-28.149		
8	102	62.398	2,200	13,200
	0	0		
		Total	2,400	14,400

NOTES:

(a) Negative (-) load values indicate compression loads; other load values are tension loads.

(b) One block represents one lifetime consisting of Steps 1 through 8, or 2,400 cycles.

(c) Tolerance on loads to be ±5%.

5.3.2.4 The above data will be obtained for at least one (1) complete load cycle.

5.3.2.5 Having acquired the desired preliminary static load data, the cyclic fatigue test will continue as described in the paragraphs which follow.

5.3.3 Fatigue testing will consist of applying the load spectrum defined in Table F-I. Testing will be conducted one block at a time with the sequence of steps for each block as shown in the table. A total of six (6) blocks representing six (6) lifetimes of load cycles will be applied to the test brace to complete the fatigue test.

5.3.4 Steps requiring a minimum number of cycles for each block may be accomplished by manual control. The other steps will be applied with automatic control. To set up for automatic load cycling, the control system is first switched to the "manual" mode of operation to accomplish the following steps:

a. With the actuator pressurized to apply a compression load on the test brace, the appropriate pressure regulator will be manually adjusted to produce the required load plus 5%. The actuator load, measured by the load cell, will be monitored by viewing the DVM.

b. The actuator will then be pressurized to apply a tension load to the brace and the appropriate

pressure regulator adjusted to produce the required load plus 5%.

c. The comparator will be preset for automatic operation to reverse the loading each time the minimum compression or tension load is achieved.

5.3.5 The control system will be switched to the automatic mode for continuous cycling. Rate of cycling will not exceed 75 cycles per minute.

5.3.6 Applied loads, hydraulic pressures and strain gage readings from L22 and L23 only will be monitored by oscillographic recording at appropriate intervals. Loads will be adjusted when required to assure they remain within specified limits.

5.3.7 After completion of the fatigue test, the test brace will again be completely inspected to blueprint, as stated in paragraph 5.1, above.
Inspection will also record any evidence of cracking, delamination, permanent set or failure. The existence of cracking, delamination or permanent set will not necessarily mean that the part has failed, but the extent of such deterioration will be noted and recorded.

5.4 Static Test

5.4.1 The test article will be strain gaged and setup for static testing as described in paragraphs 4.1 and 4.4 of this document.

5.4.2 Static Compression Load Test, Limit

5.4.2.1 With zero load applied to the test brace, all strain gage bridge circuits will be electrically balanced and resistance calibrated using appropriate shunt resistors.

5.4.2.2 A static compression limit load of 104,200 pounds will be applied in increments not greater than 20% of limit load. Loading will be held at each increment long enough to record strain measurements on all strain gages plus the load cell reading. Similar data will be obtained at approximately the same load levels while reducing the compression load to zero.

5.4.3 Static Tension Load Test, Limit

5.4.3.1 The procedure for the limit static compression load test will be repeated except a limit tension load of 102,400 pounds will be applied in increments not greater than 20%.

5.4.4 Static Compression Load Test, Ultimate

5.4.4.1 For ultimate load tests, selected strain gages, limited to 17 channels of data, will be wired to a Honeywell cathode ray tube recording oscillograph. One channel of applied load, as measured by the load cell, will also be fed into the oscillograph.

5.4.4.2 With the oscillograph operating for continuous recording, an ultimate compression load of 156,300 pounds (minimum) will be gradually applied and held for three (3) seconds, then reduced to zero load.

5.4.5 Static Tension Load Test, Ultimate

5.4.5.1 The procedure used for the ultimate static compression load testing will be repeated except an ultimate tension load of 153,600 pounds (minimum) will be applied and held for three (3) seconds, then released. The selected strain gages need not be the same ones as selected for the compression load test.

5.4.6 After completing the static testing, the test brace will be inspected for evidence of permanent set by making the dimensional checks specified in paragraphs 5.2.2 (a) and (b). Visual inspection will record existence of cracks, delamination or failure. No failure is allowed; however, cracks, permanent set, and delamination are permitted.

6.0 <u>FINAL REPORT</u>

6.1 Upon completion of all testing and post test inspection, a final engineering test report will be prepared.

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